



## How to use CFD for long-term energy assessments

**Bechmann, Andreas**

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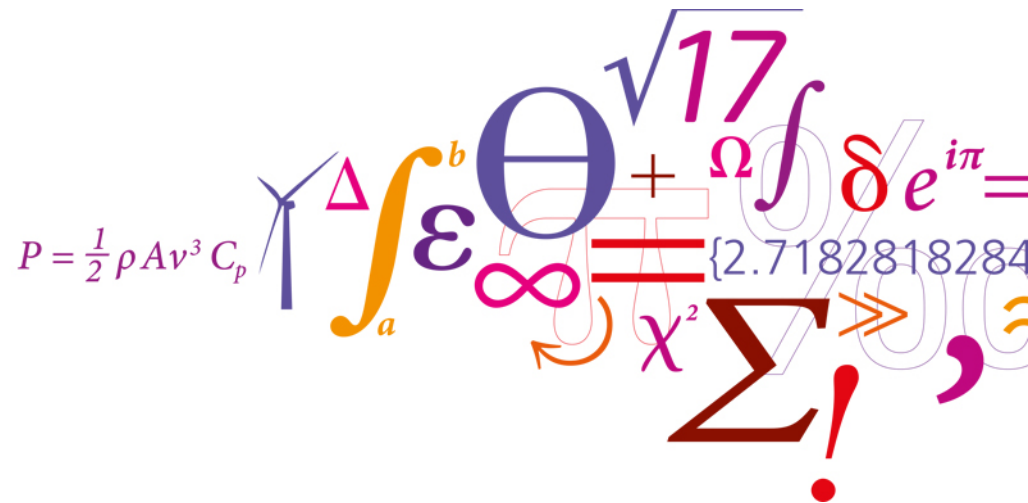
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# How to use CFD for long-term energy assessments

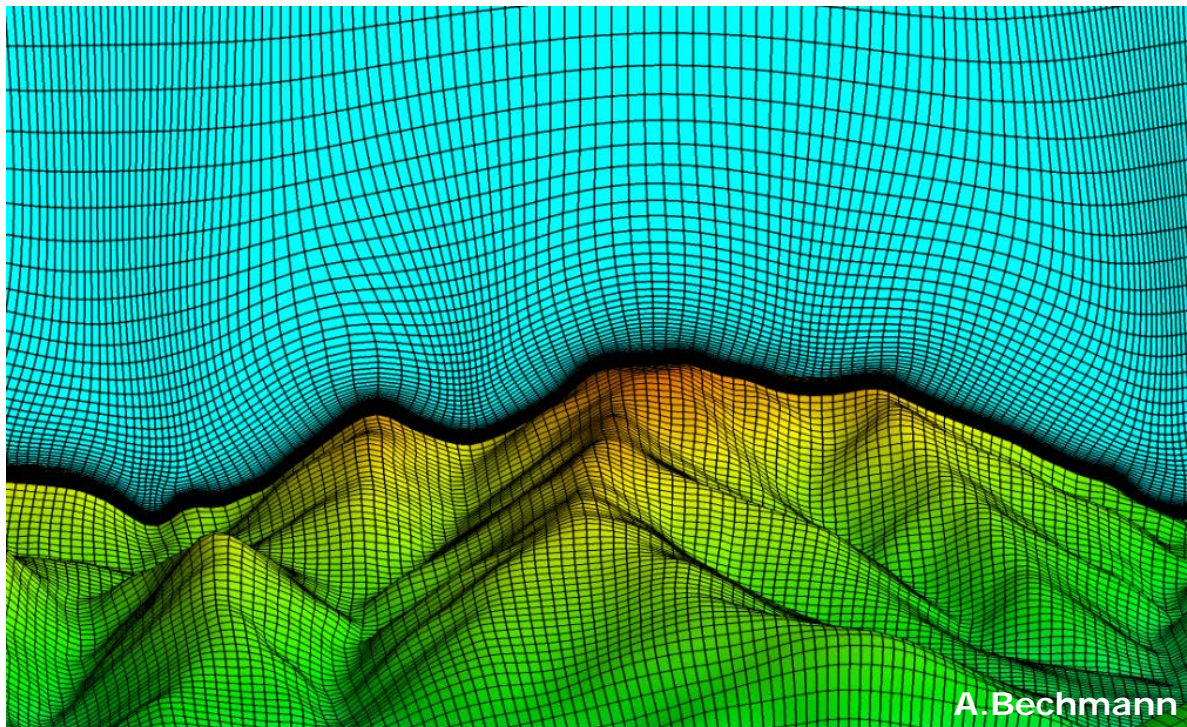
Andreas Bechmann

08/04-2014



# How to use CFD for long-term energy assessments

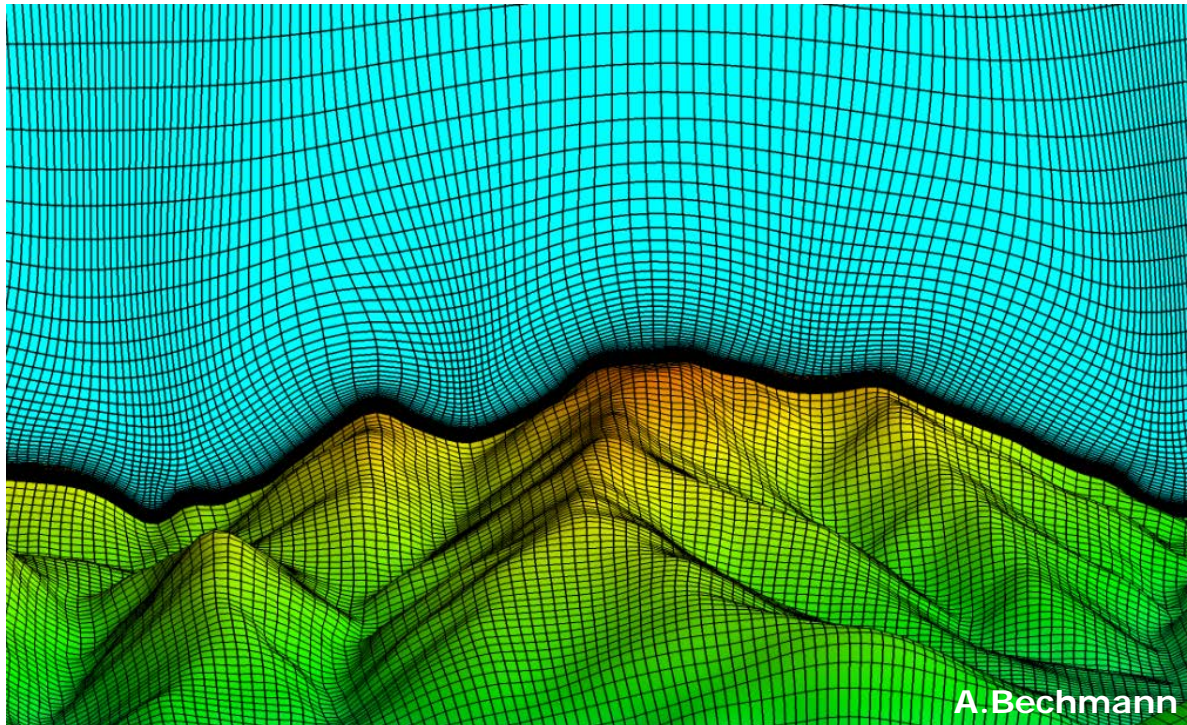
1. Modelling of Wind Resources
2. Example: WAsP CFD
3. Example: Forestry modeling based on aerial LIDAR scans





# How to use CFD for long-term energy assessments

1. Modelling of Wind Resources
2. Example: WAsP CFD
3. Example: Forestry modeling based on aerial LIDAR scans



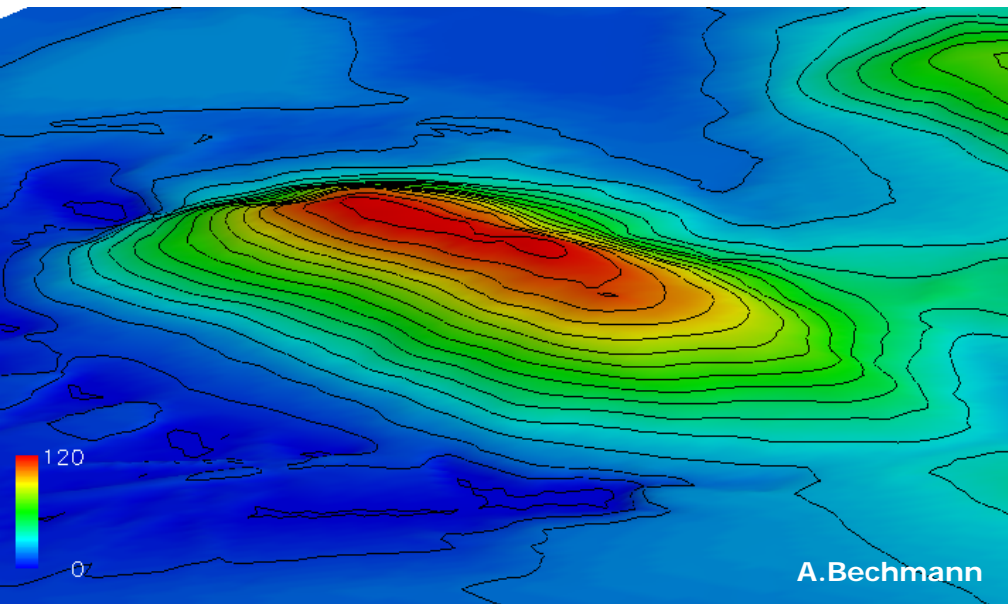


# Modelling of wind resources

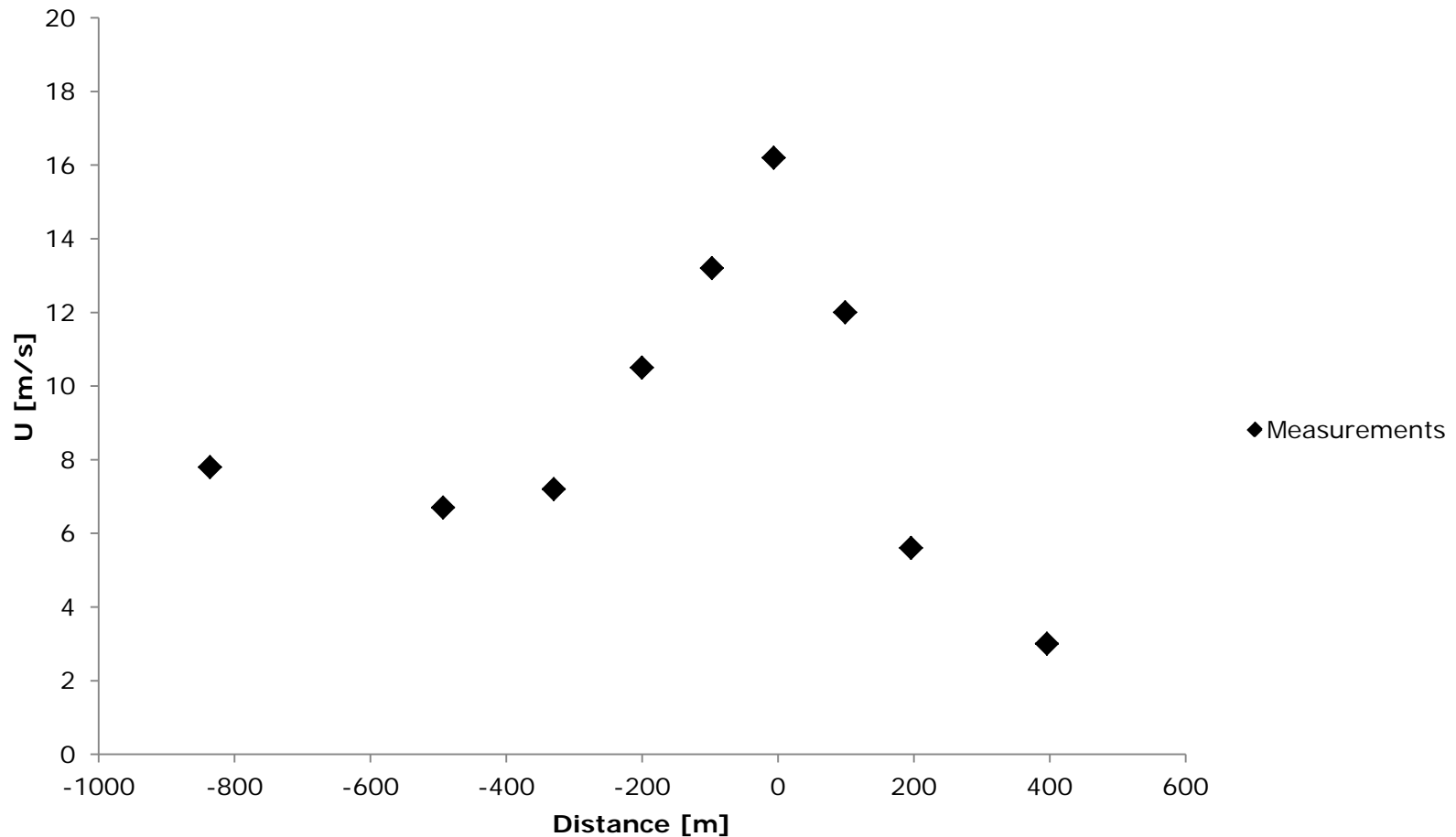
RANS equations:

$$\frac{\partial(\bar{u}_i \bar{u}_j)}{\partial x_j} = -\frac{1}{\rho} \frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ (\nu_T) \left( \frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) \right] - C_d L A D u_i |U|$$

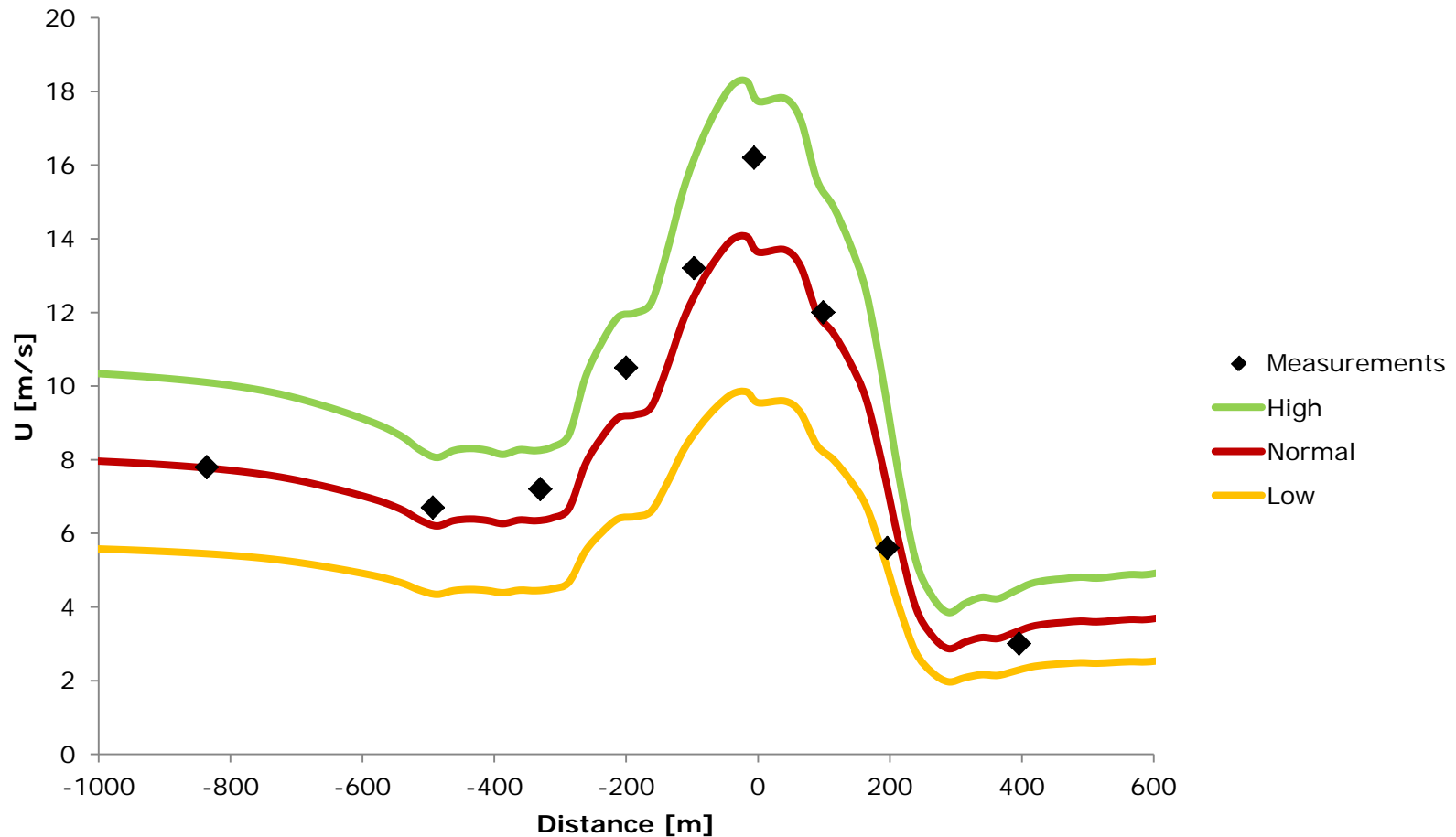
Askervein Experiment 1983:



# Modelling of wind resources

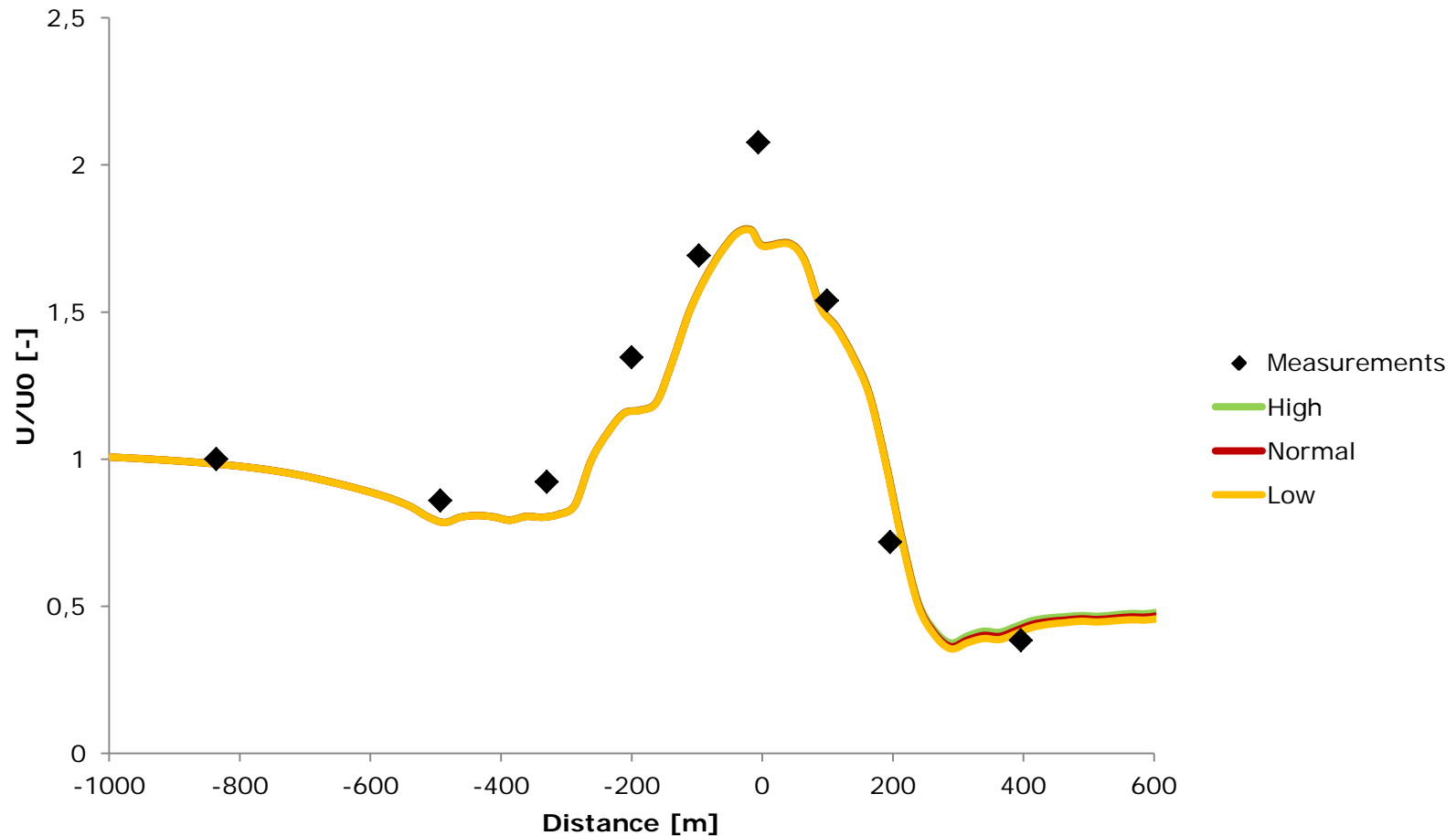


# Modelling of wind resources





# Modelling of wind resources



# Modelling of wind resources

Reynolds number:  $Re = U_0 L_0 / \nu$

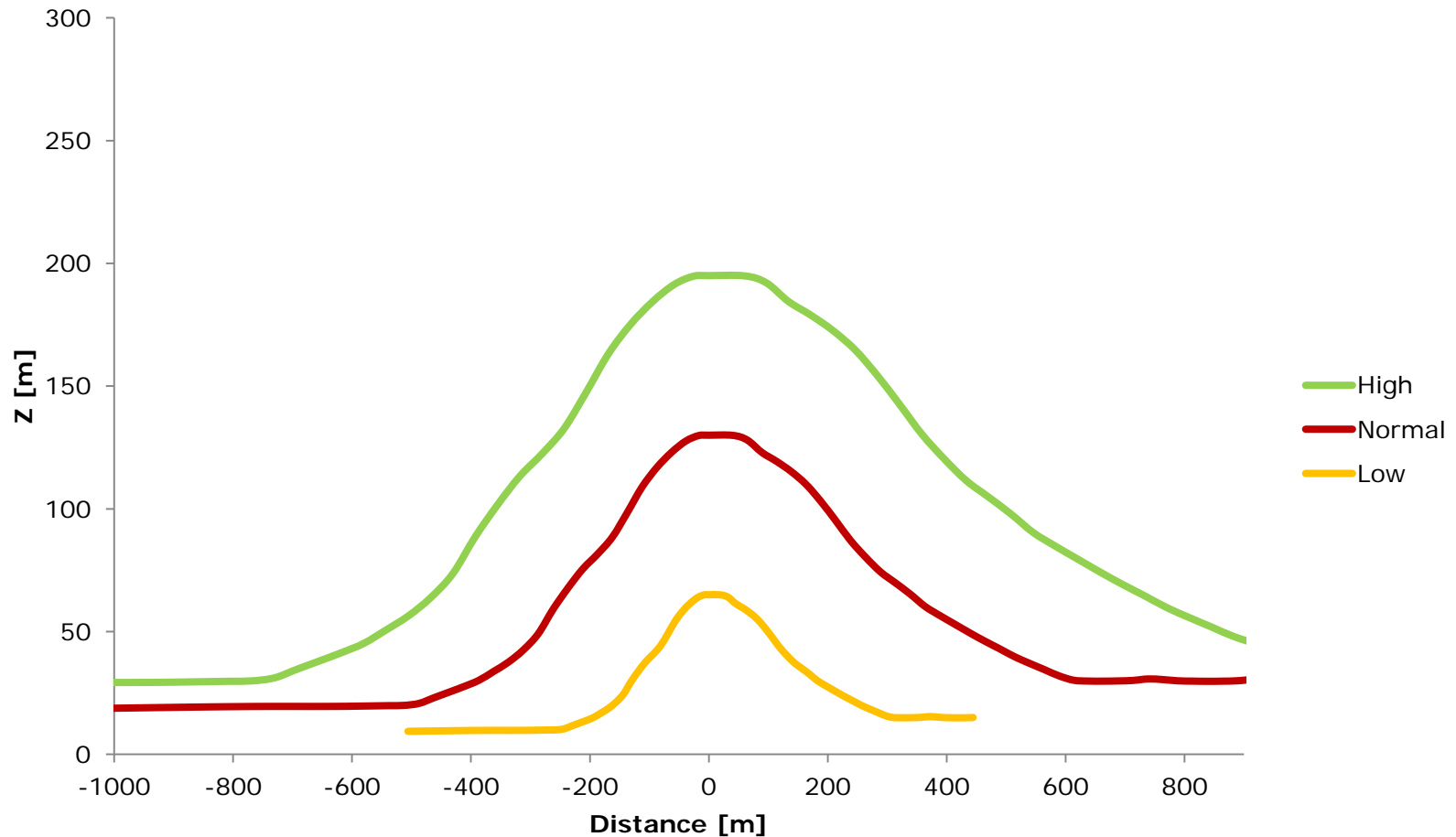
$$\Delta S = U/U_0 \text{ (Speedup)}$$

Jensen number =  $L_0/z_0$

$$\Delta L = L/L_0$$

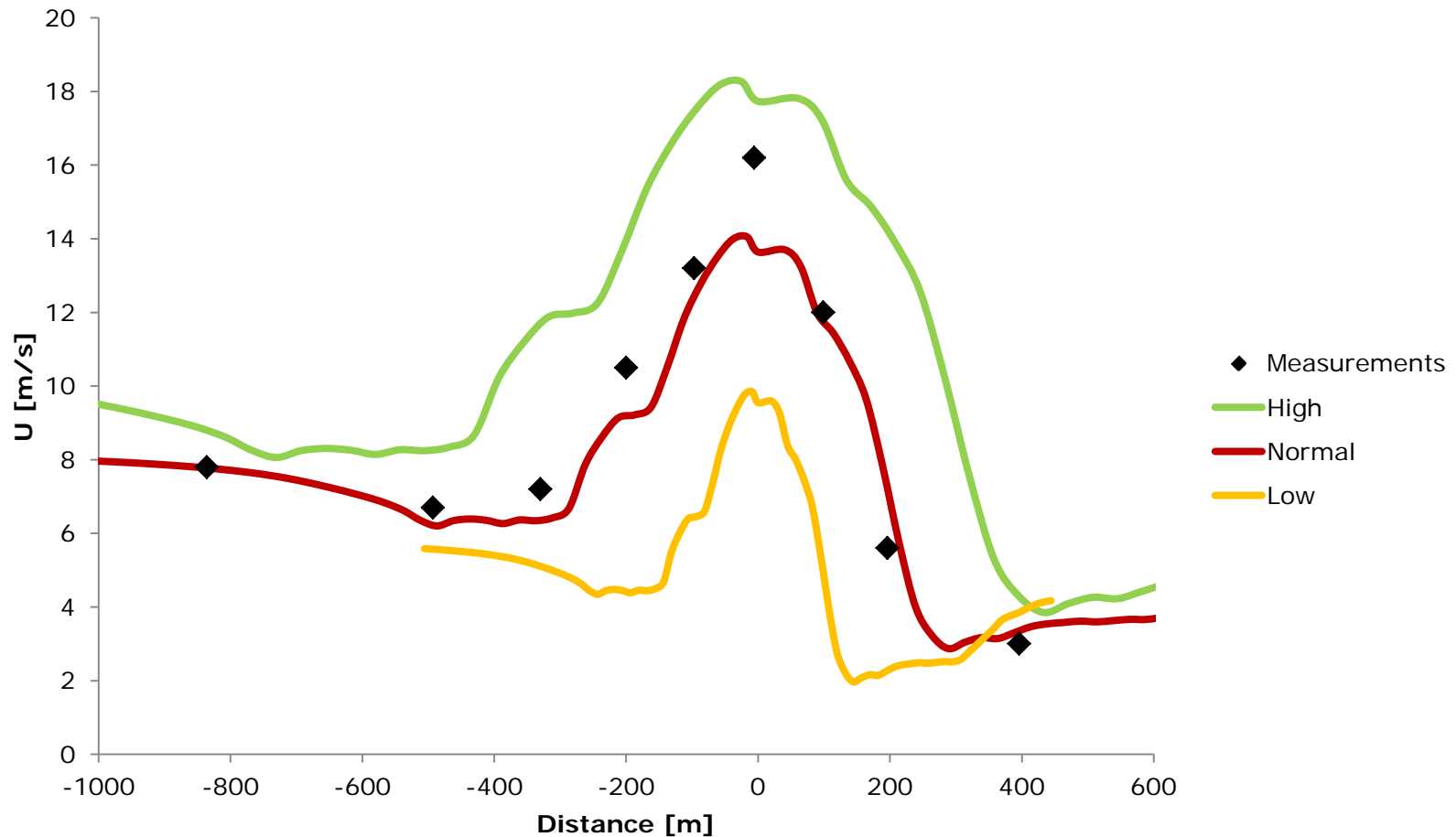


# Modelling of wind resources



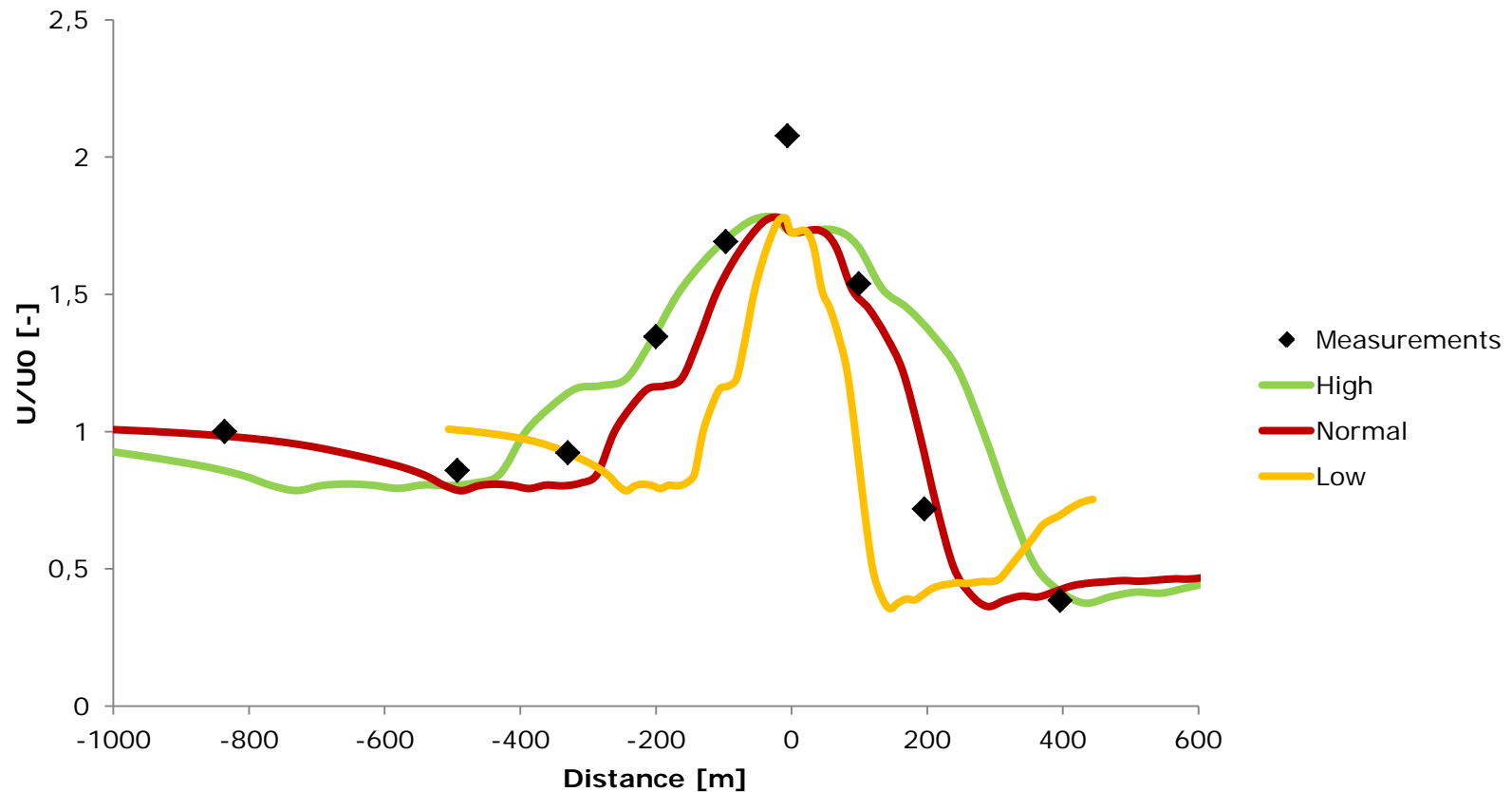


# Modelling of wind resources



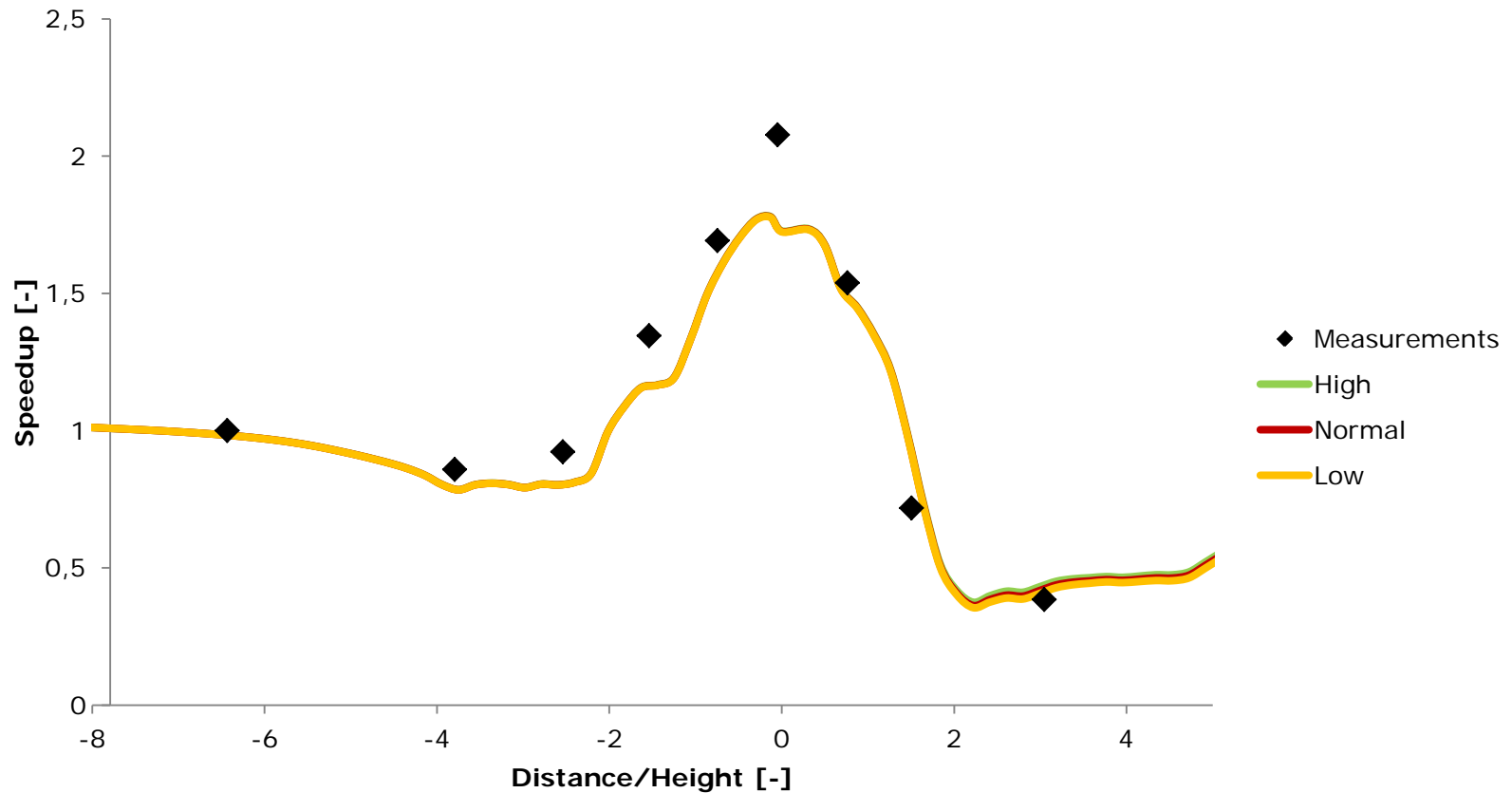
# Modelling of wind resources

## Askervein, Line A



# Modelling of wind resources

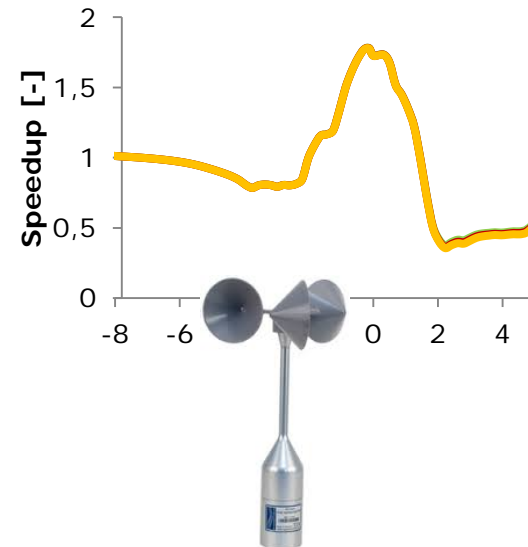
## Askervein, Line A





# Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy
2. A model cannot predict wind resources; it extrapolates measurements



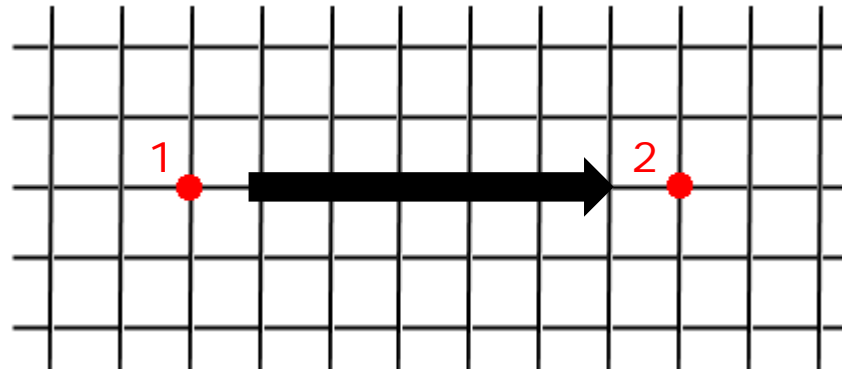
# Extrapolate wind resources

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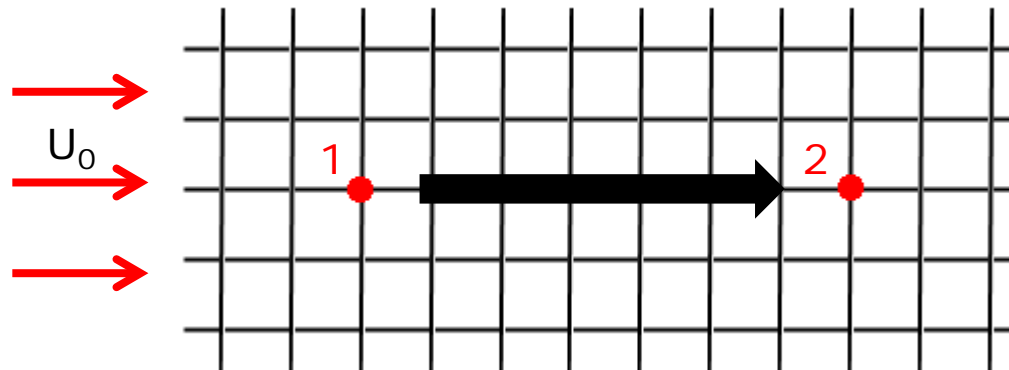




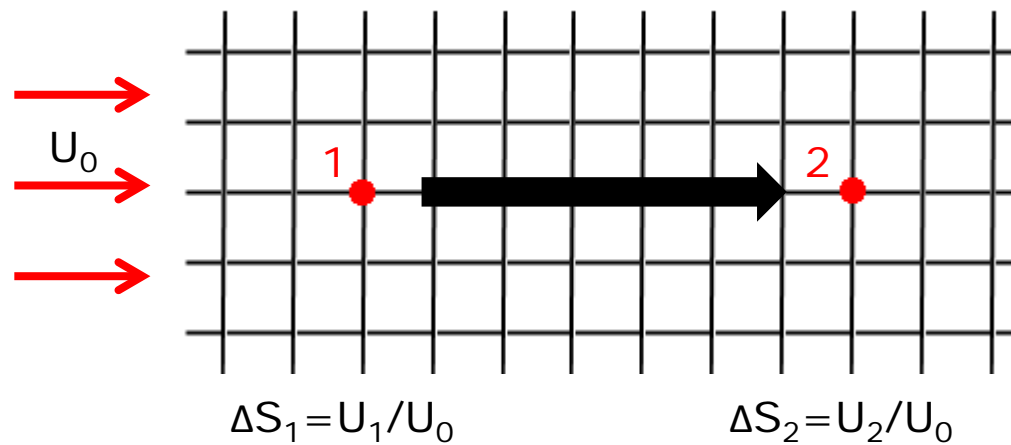
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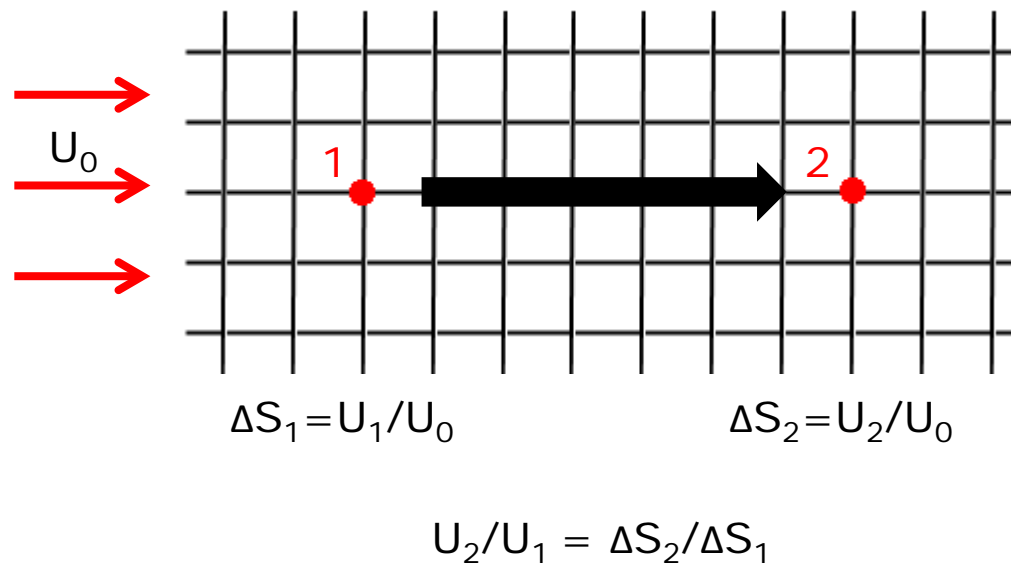
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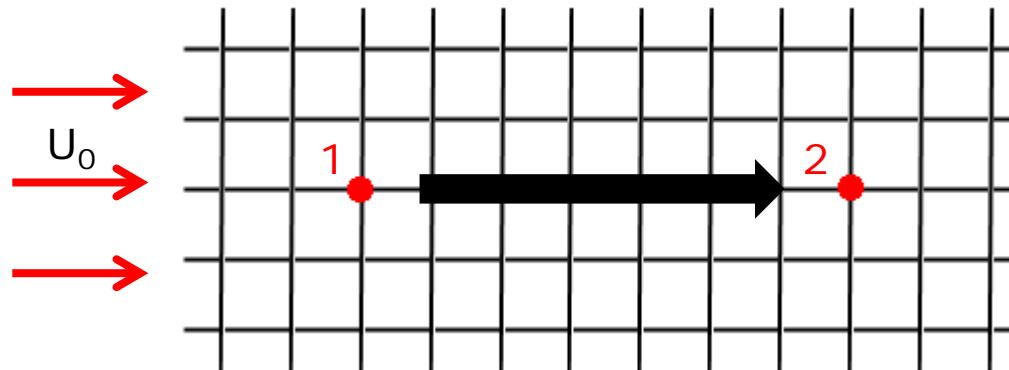
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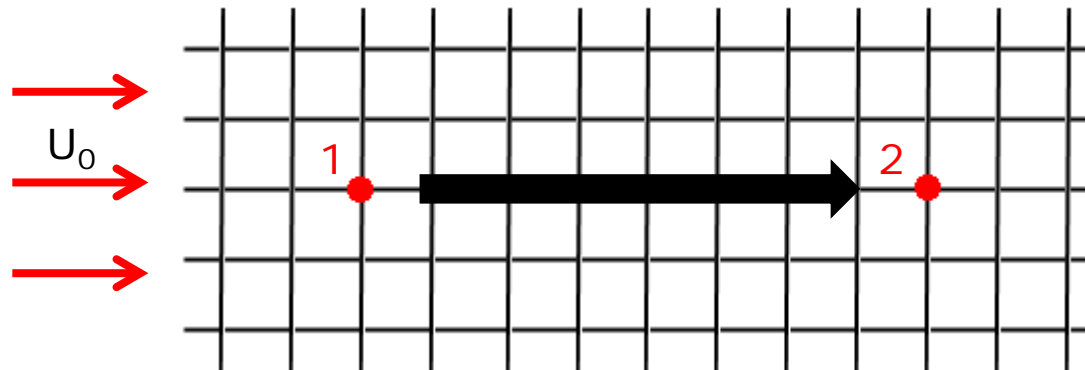


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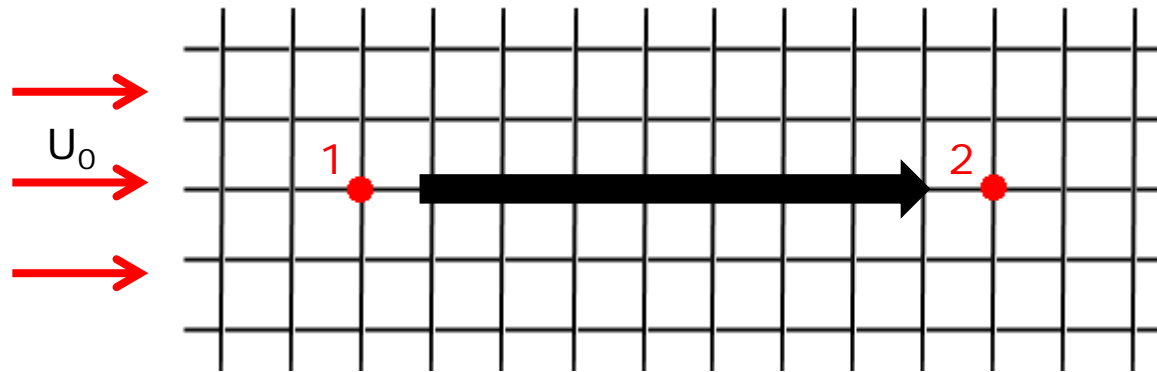
$$U_2/U_1 = \Delta S_2/\Delta S_1$$

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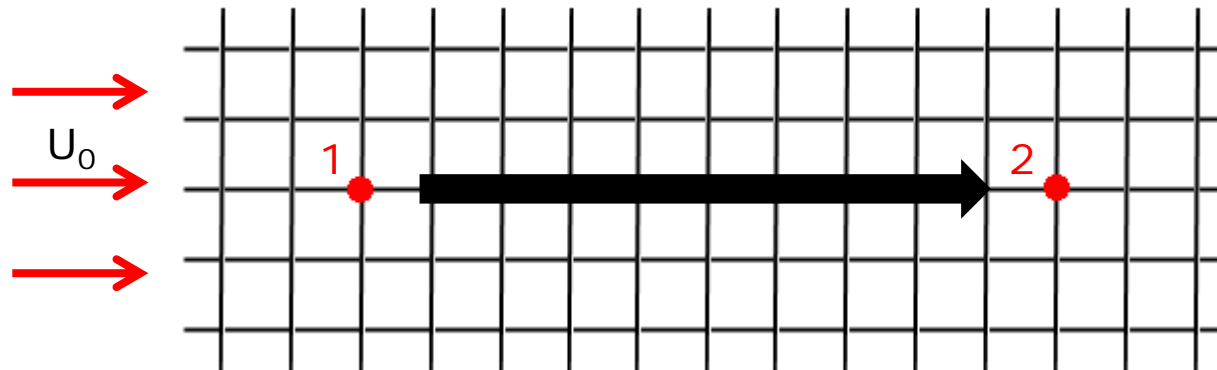
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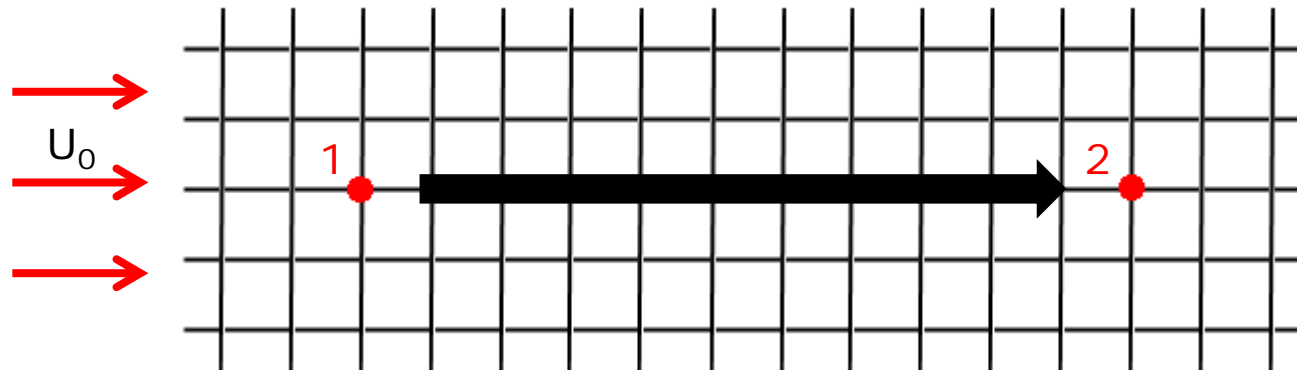


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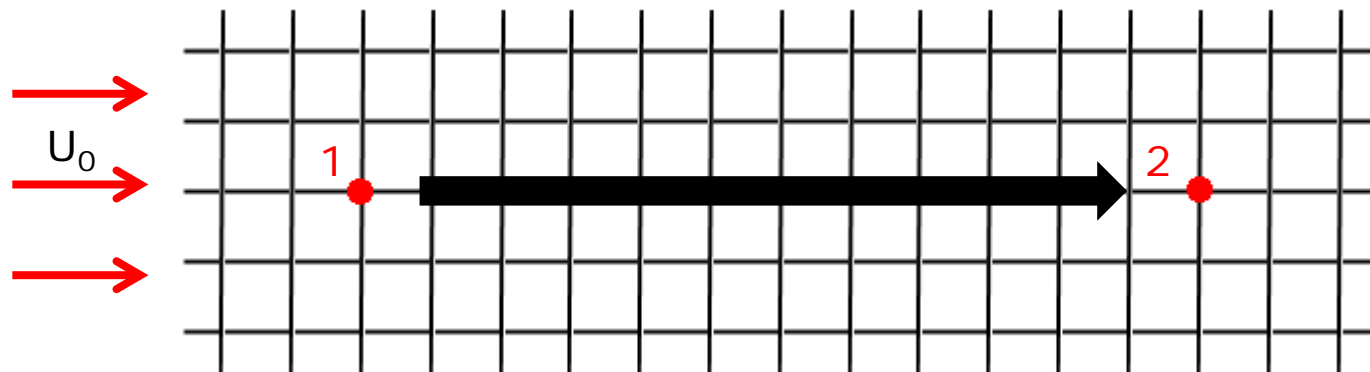


$$U_2/U_1 = \Delta S_2/\Delta S_1$$

# Extrapolate wind resources

## Problem:

1. Large scale effects omitted (Coriolis, Bouyancy)
2. Large computational resources



## Solutions:

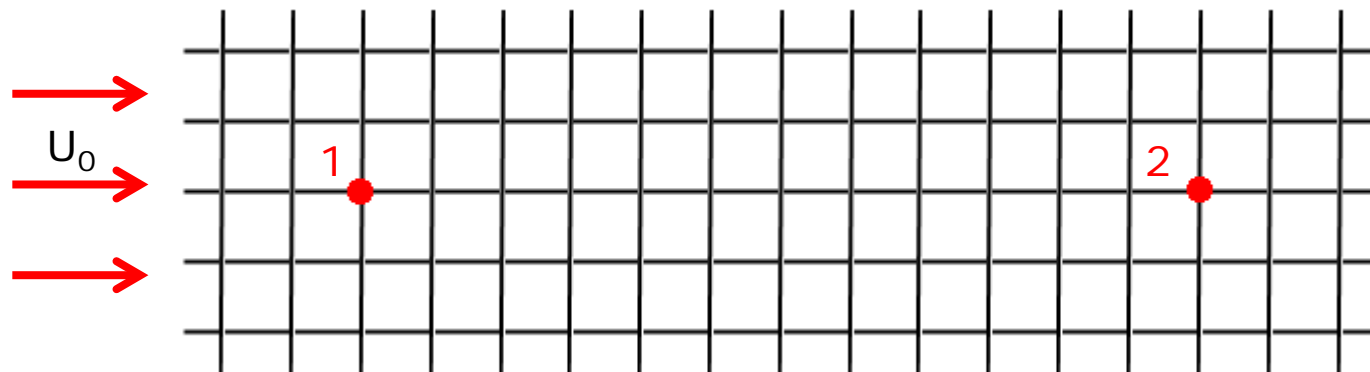
1. Do nothing
2. Micro-Meso scale coupling
3. Micro model -> meso scales
4. Meso model -> micro scales

$$U_2/U_1 = \Delta S_2/\Delta S_1$$

# Extrapolate wind resources

## Problem:

1. Large scale effects omitted (Coriolis, Bouyancy)
2. Large computational resources



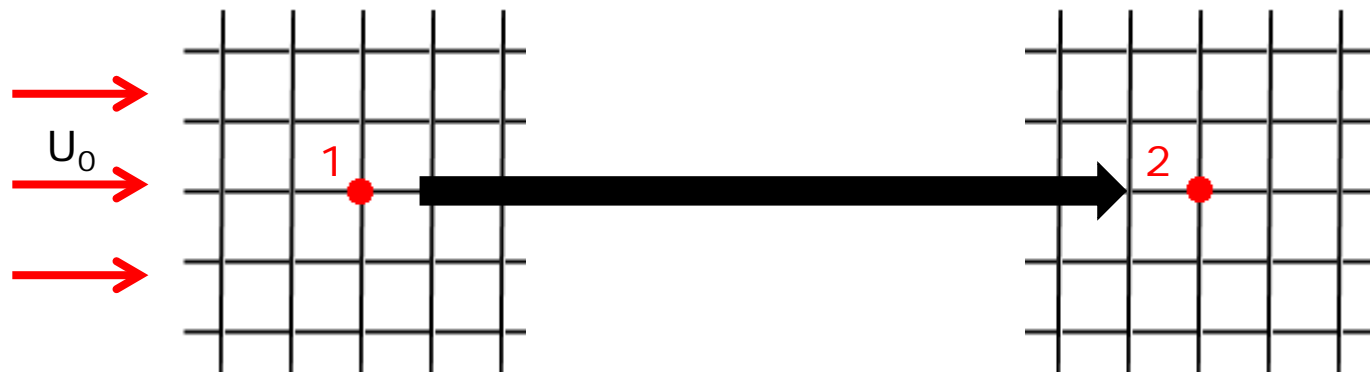
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# Extrapolate wind resources

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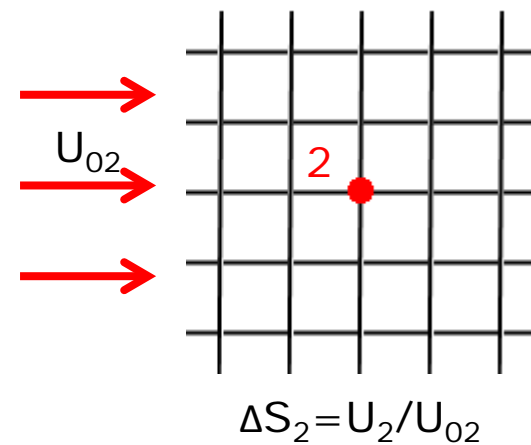
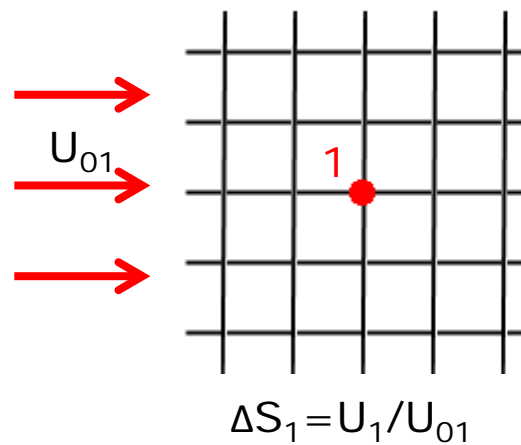
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## Solutions:

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# Extrapolate wind resources

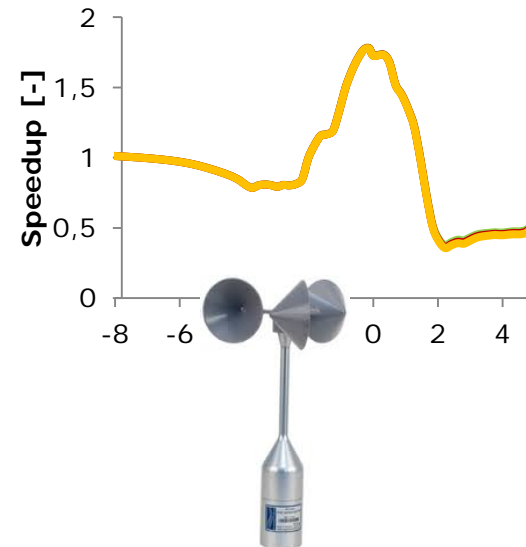


$$U_2 / U_1 = \Delta S_2 / \Delta S_1 * U_{02} / U_{01}$$

Micro      Meso

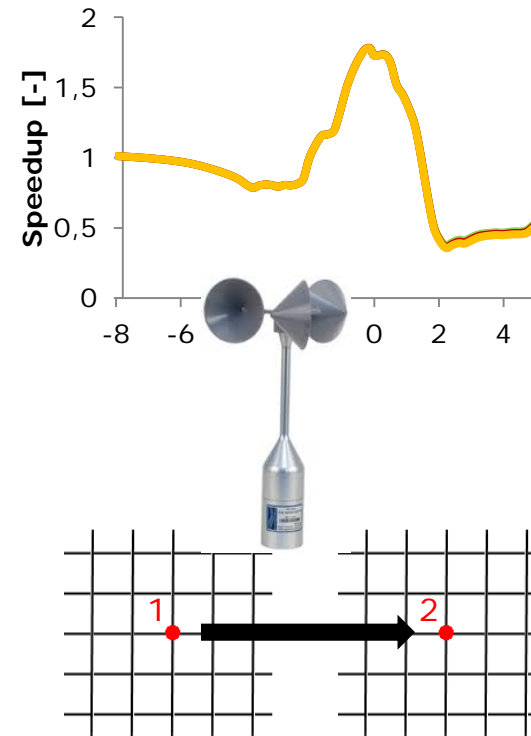
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1. The flow is Re-independent when omitting Coriolis and Buoyancy
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# Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy
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3. A method to couple micro- and meso-scales is needed





# Micro - Meso coupling

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Micro scale inflow:

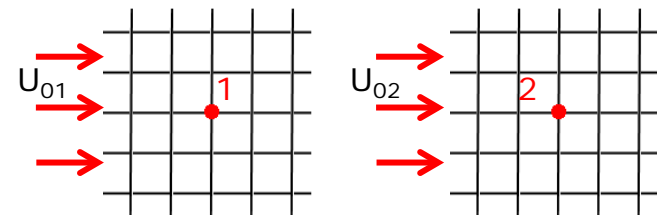
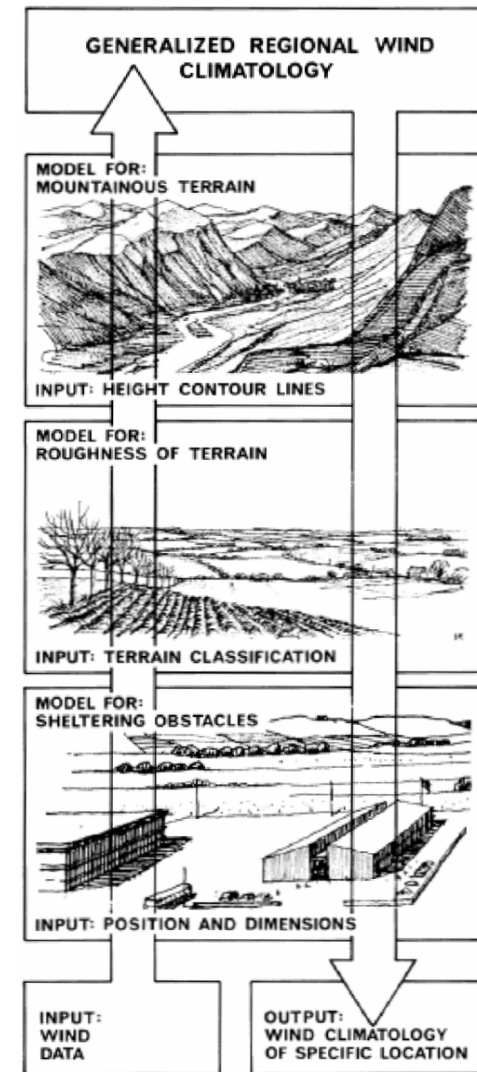
$$\frac{\langle M \rangle}{u_{*0}} = \frac{1}{\kappa} \ln \left( \frac{z}{z_0} \right) = C_D^{-1/2}$$

Meso scale, Geo. drag Law:

$$\frac{G}{u_{*0}} \cos \theta = \frac{1}{\kappa} \left[ \ln \left( \frac{u_{*0}}{|f_c| z_0} \right) - A \right] = C_D^{-1/2}$$

1. The inflow is defined by a surface  $z_{01}$
2.  $z_{01}$  represents a "large-scale" terrain roughness

- The inflow should balance the "large-scale"  $z_{01}$ .
- The CFD model simulates the micro-scale varians from the meso-scale mean.



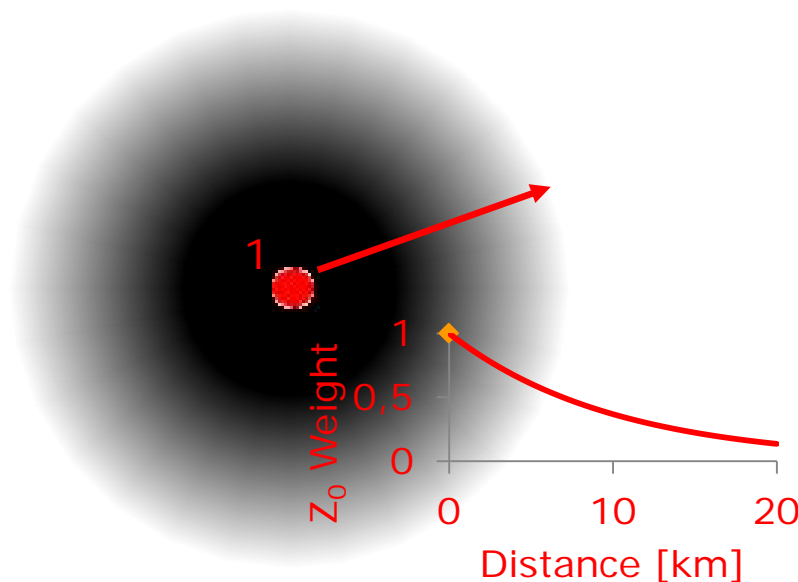
# Micro - Meso coupling

**Large-scale roughness length:**

Rossby radius:  $G/f \geq 10\text{km}$

**Inflow boundary condition:**

For homogeneous farfield terrain

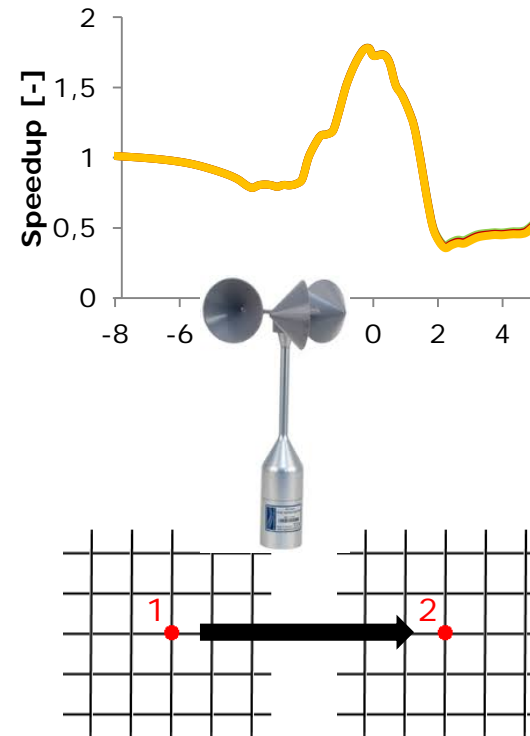


$$\frac{\langle M \rangle}{u_{*0}} = \frac{1}{\kappa} \ln \left( \frac{z}{z_0} \right) \quad k = \frac{u_{*0}^2}{\sqrt{C_\mu}}$$

- The inflow should balance the “large-scale”  $z_{01}$ .
- The CFD model simulates the micro-scale  
varians from the meso-scale mean.

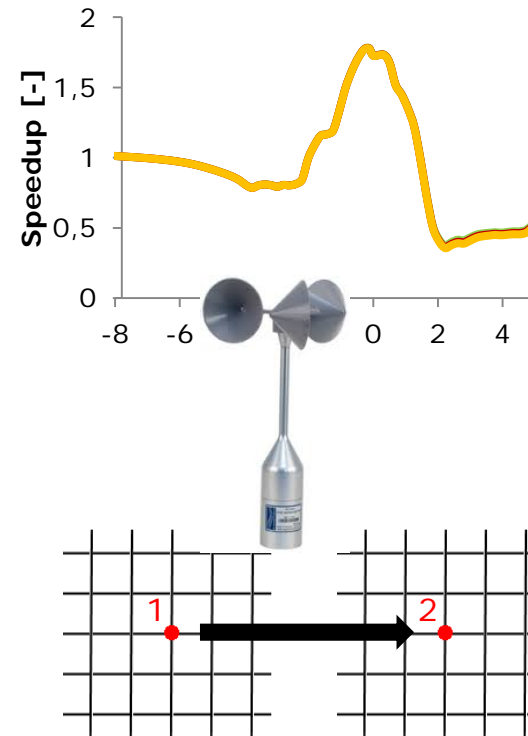
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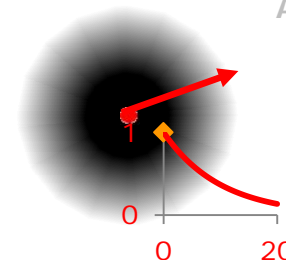


# Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy
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3. A method to couple micro- and meso-scales is needed
4. Farfield conditions should balance the meso-scale mean

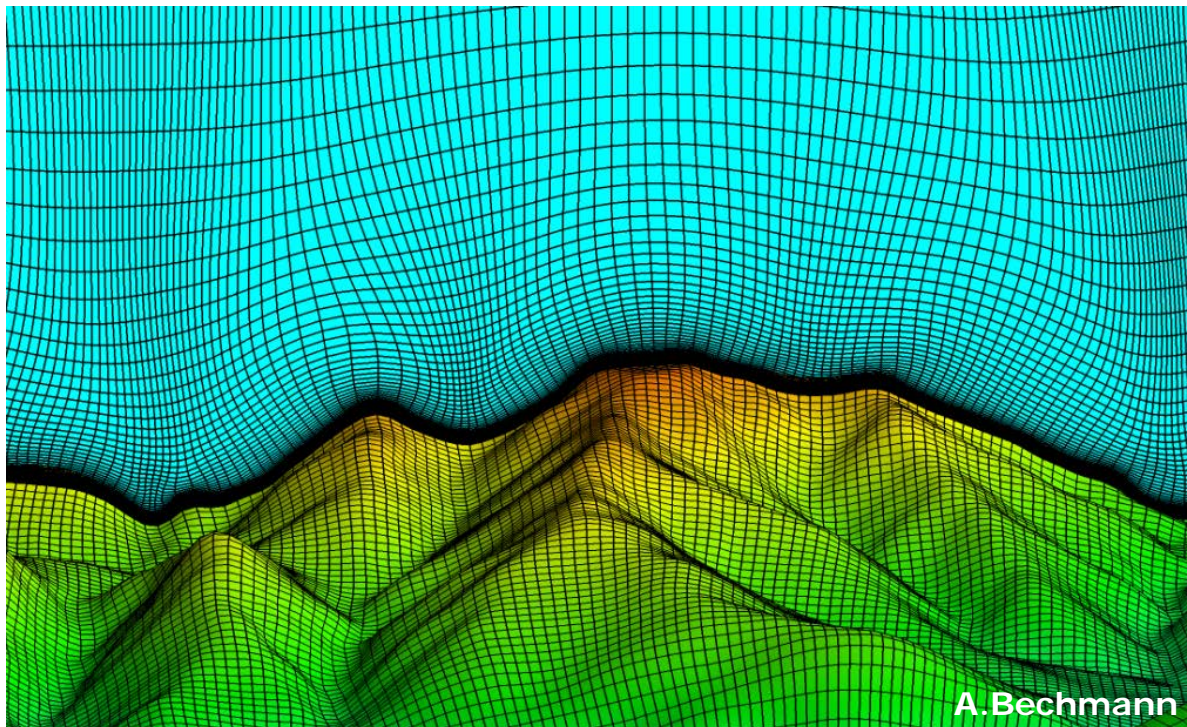


A.Bechmann



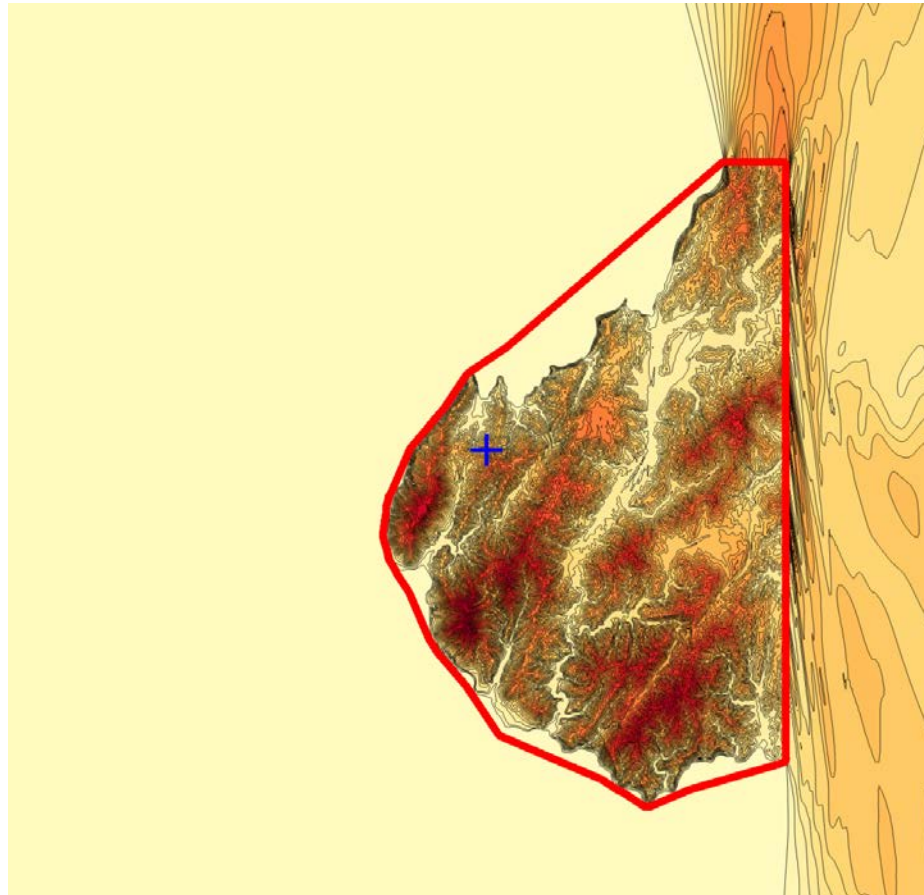
# How to use CFD for long-term energy assessments

1. Modelling of Wind Resources
2. **Example: WAsP CFD**
3. Example: Forestry modeling based on aerial LIDAR scans



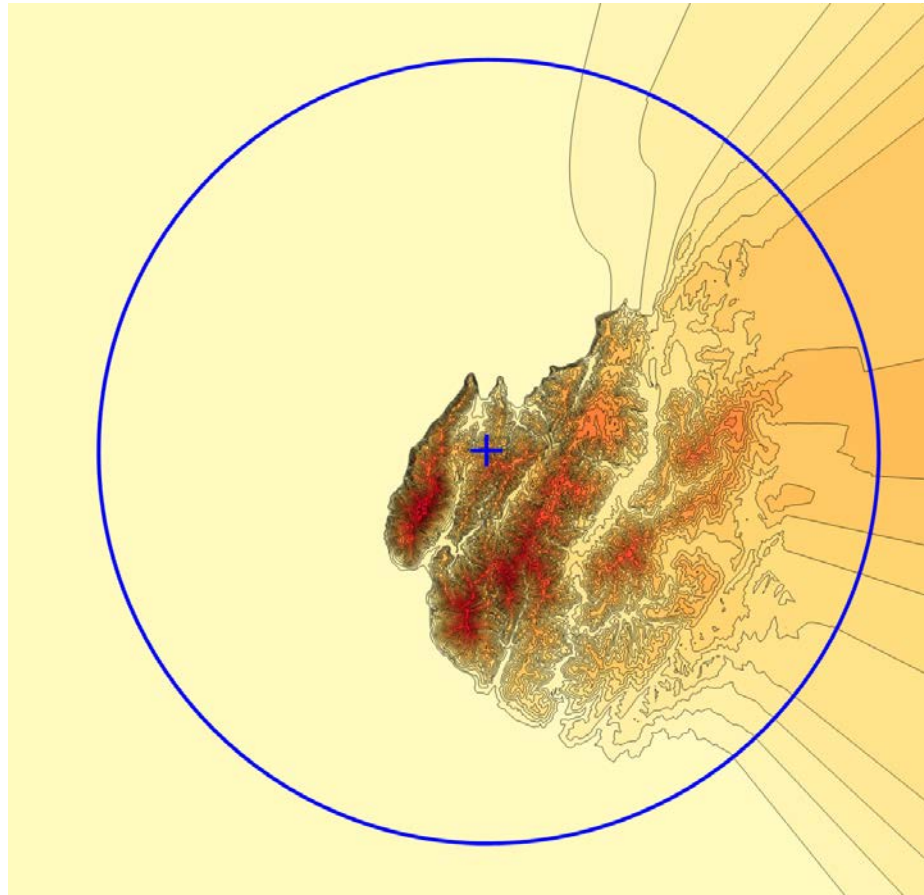
# Example: Prepare Terrain

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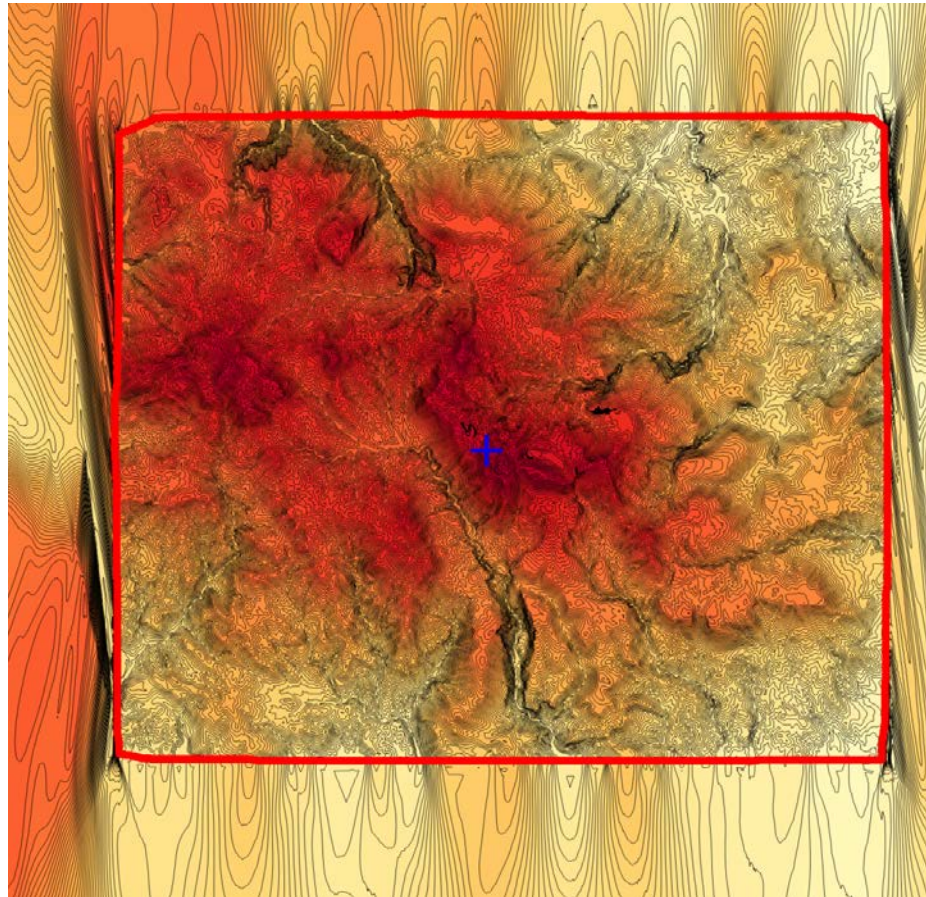




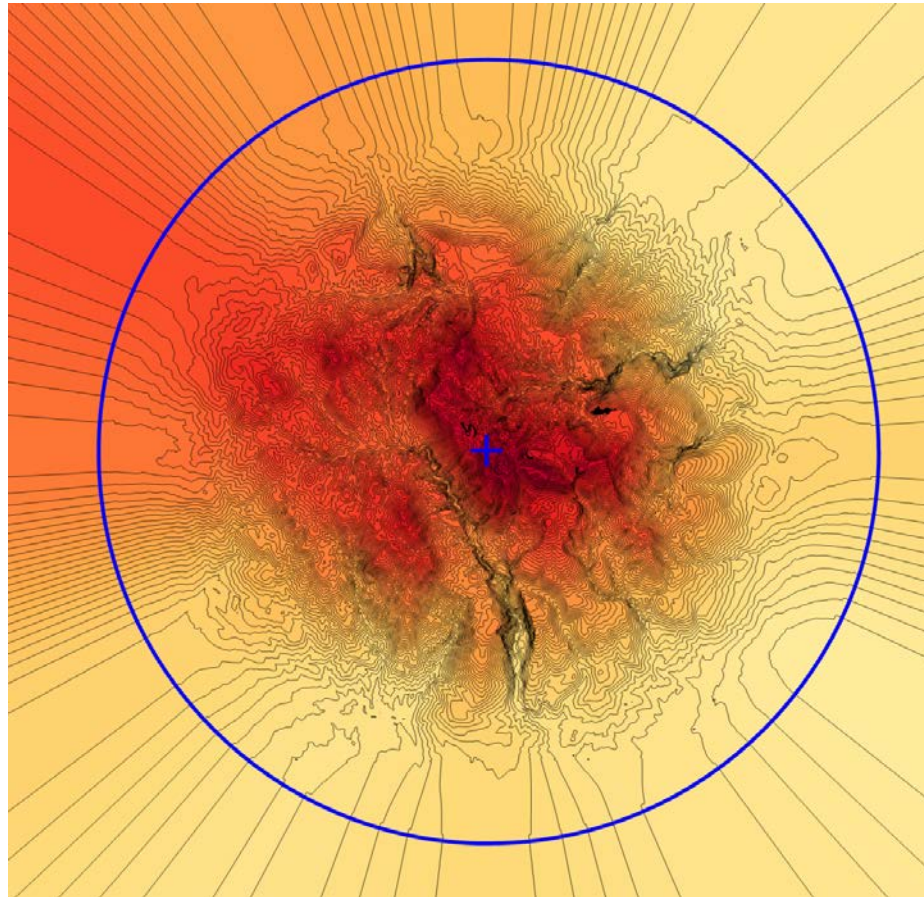
## Example: Prepare Terrain



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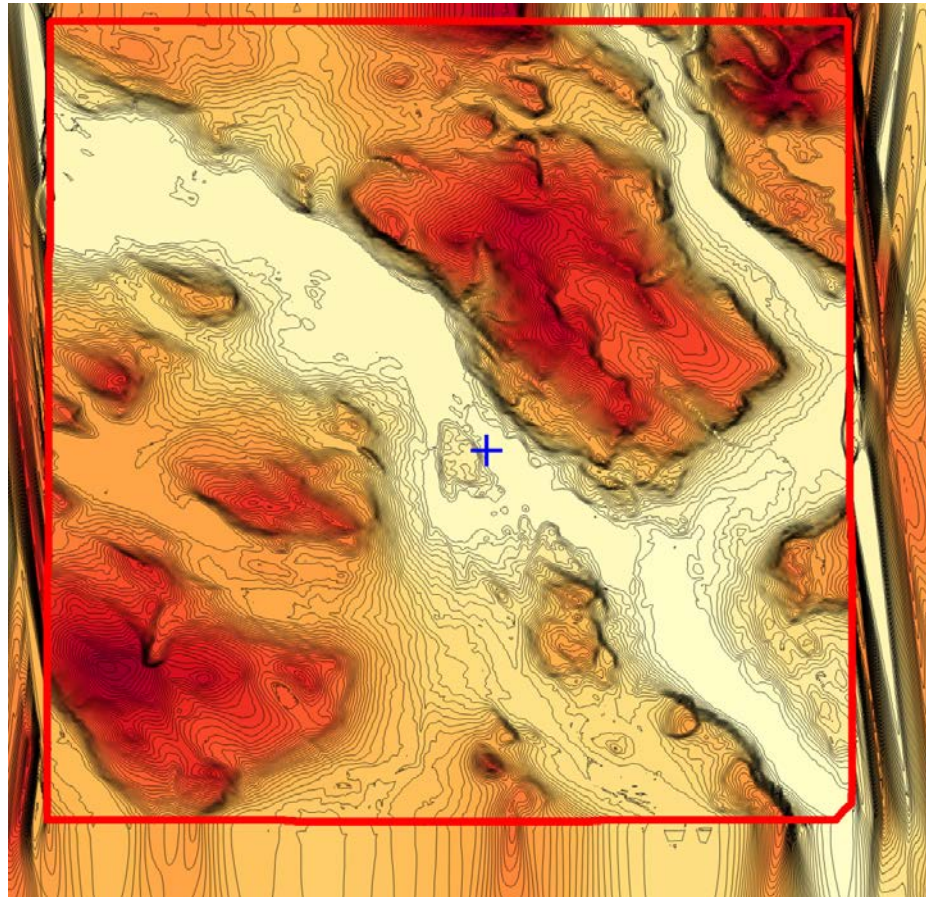


## Example: Prepare Terrain

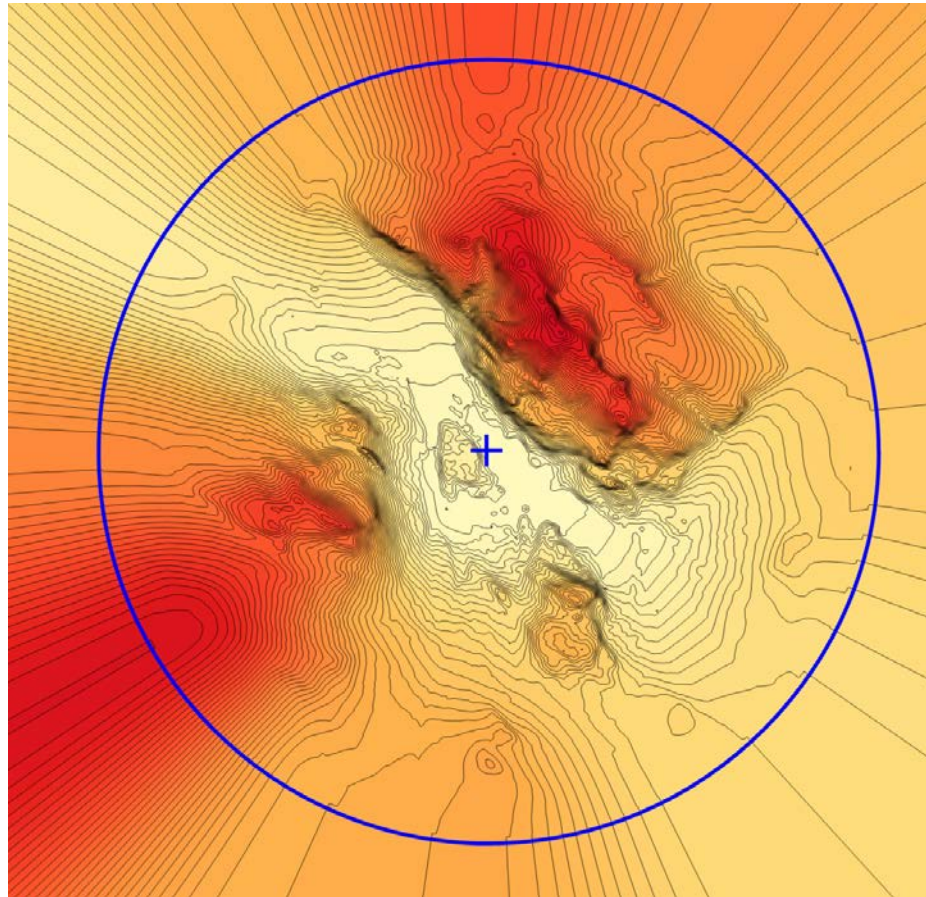




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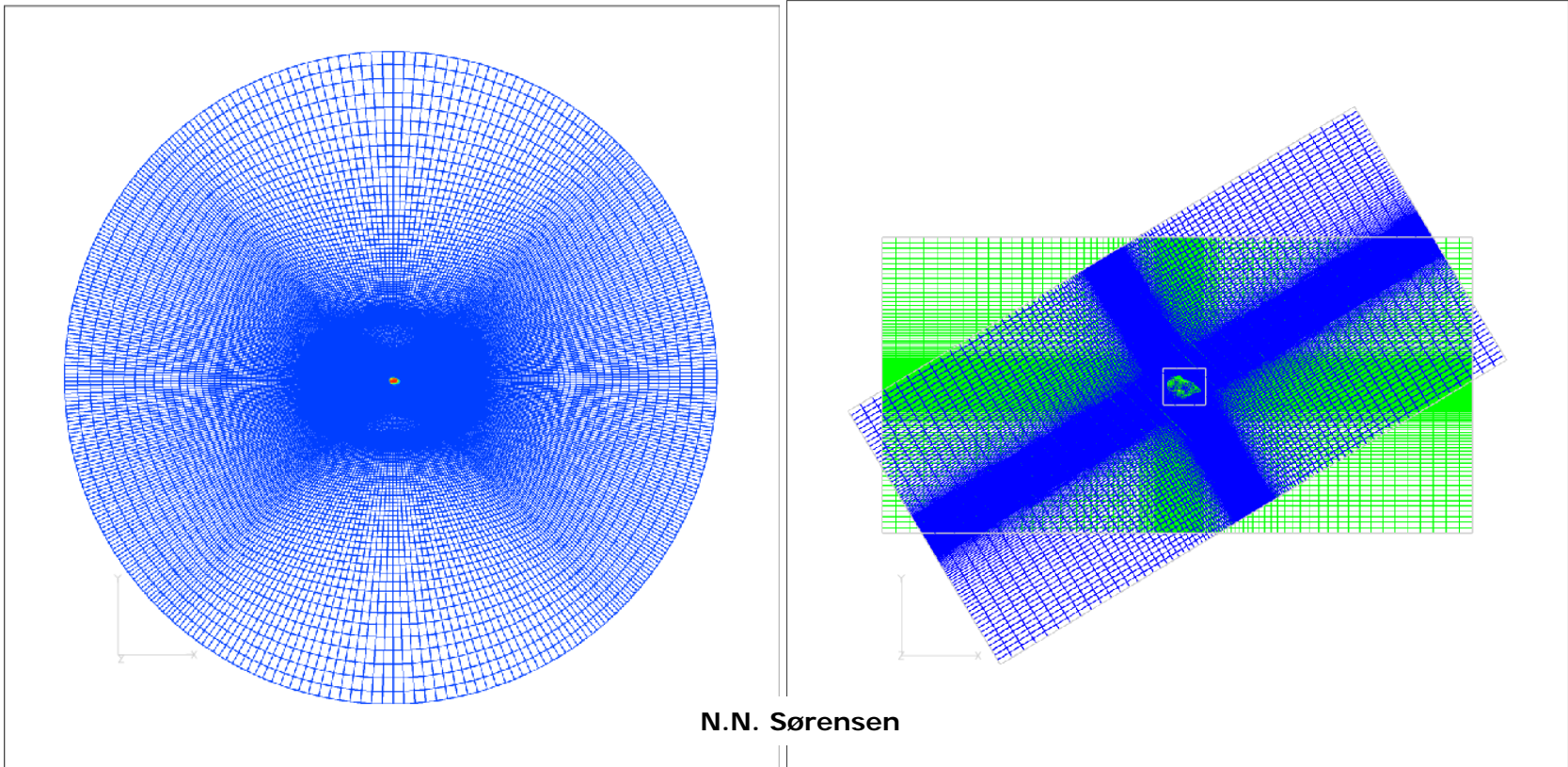


## Example: Prepare Terrain



# Example: Mesh

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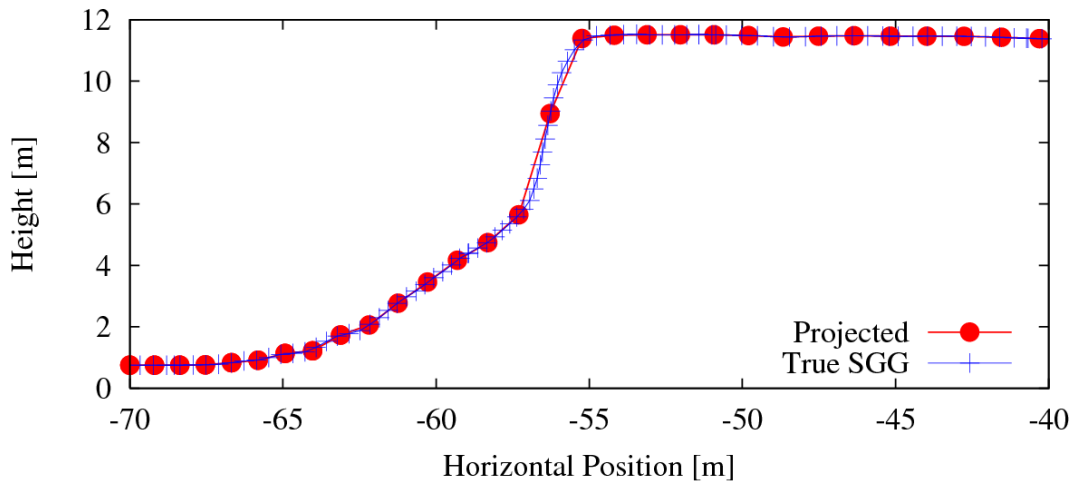
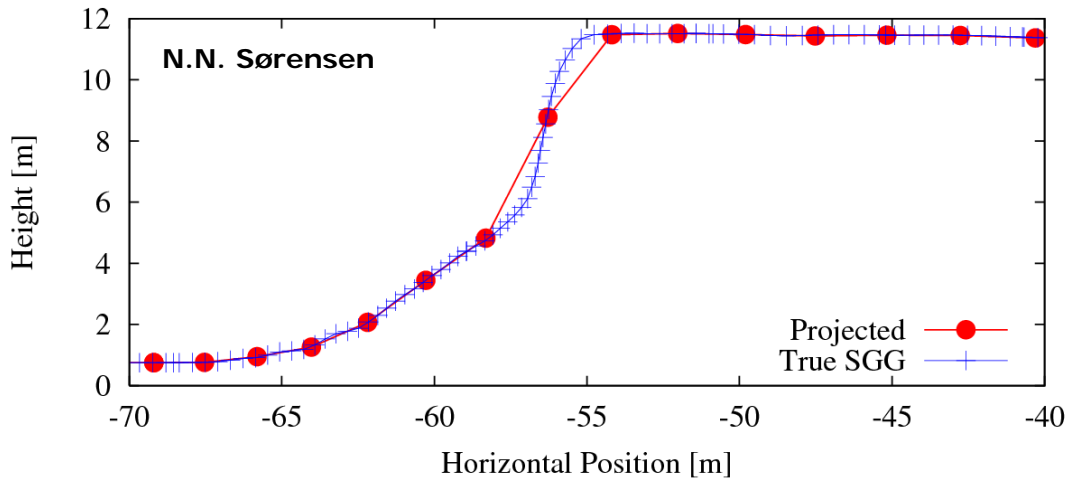
**One domain for all comp.**

**A dedicated mesh for each direction**



# Example: Mesh

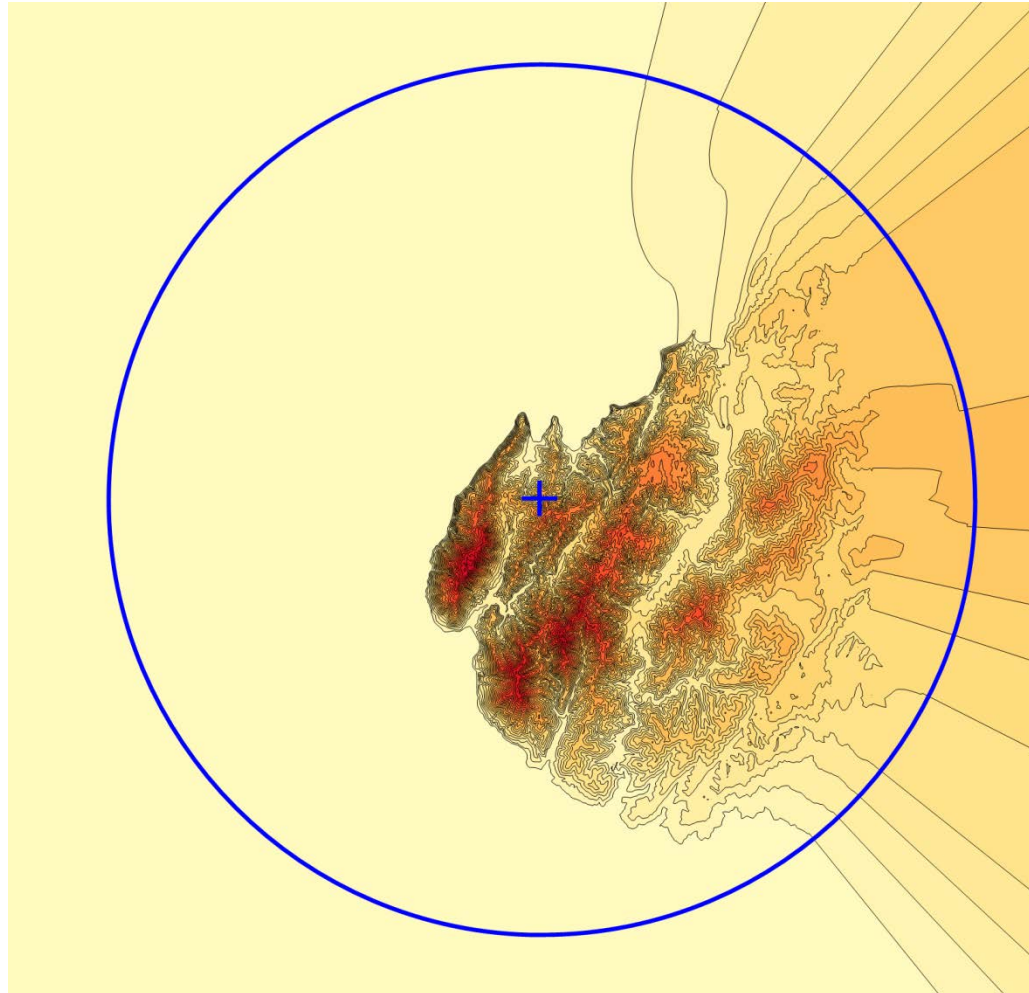
- Simple projection of a surface grid onto terrain, leads to coarse cells at steep slopes. Not suited for grid convergence studies.





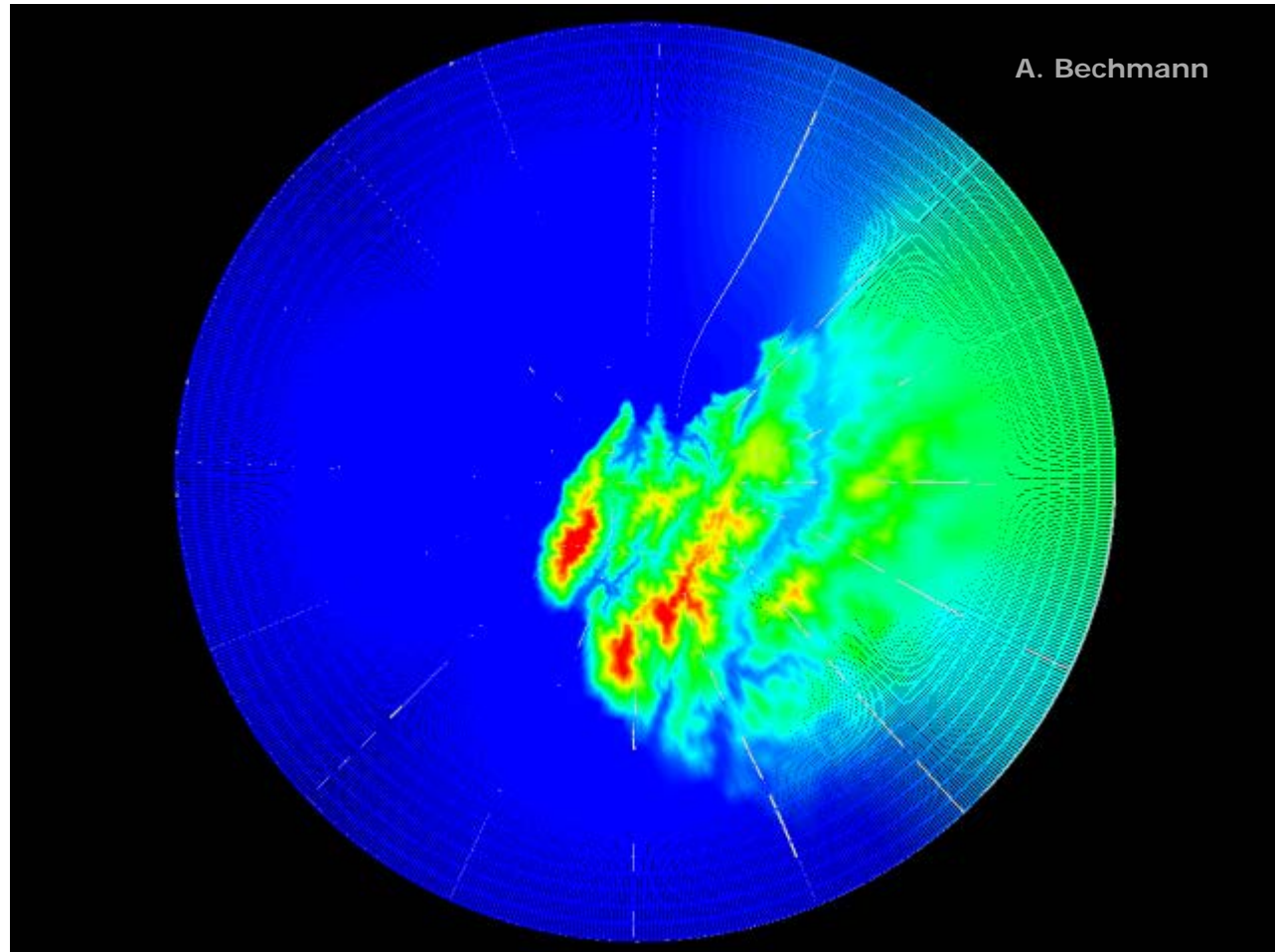
# Example: Mesh

34km



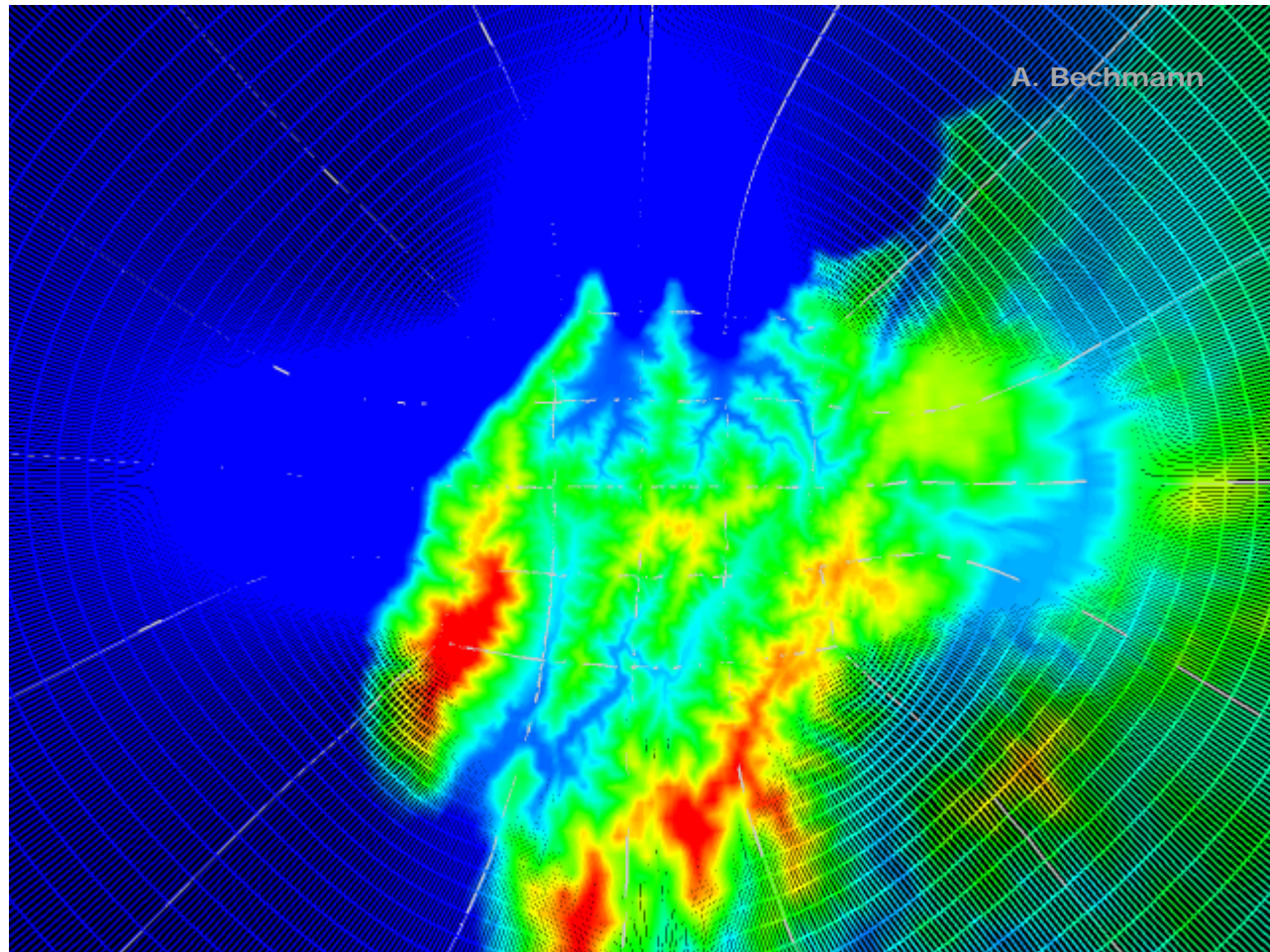
# Example: Mesh

34km



# Example: Mesh

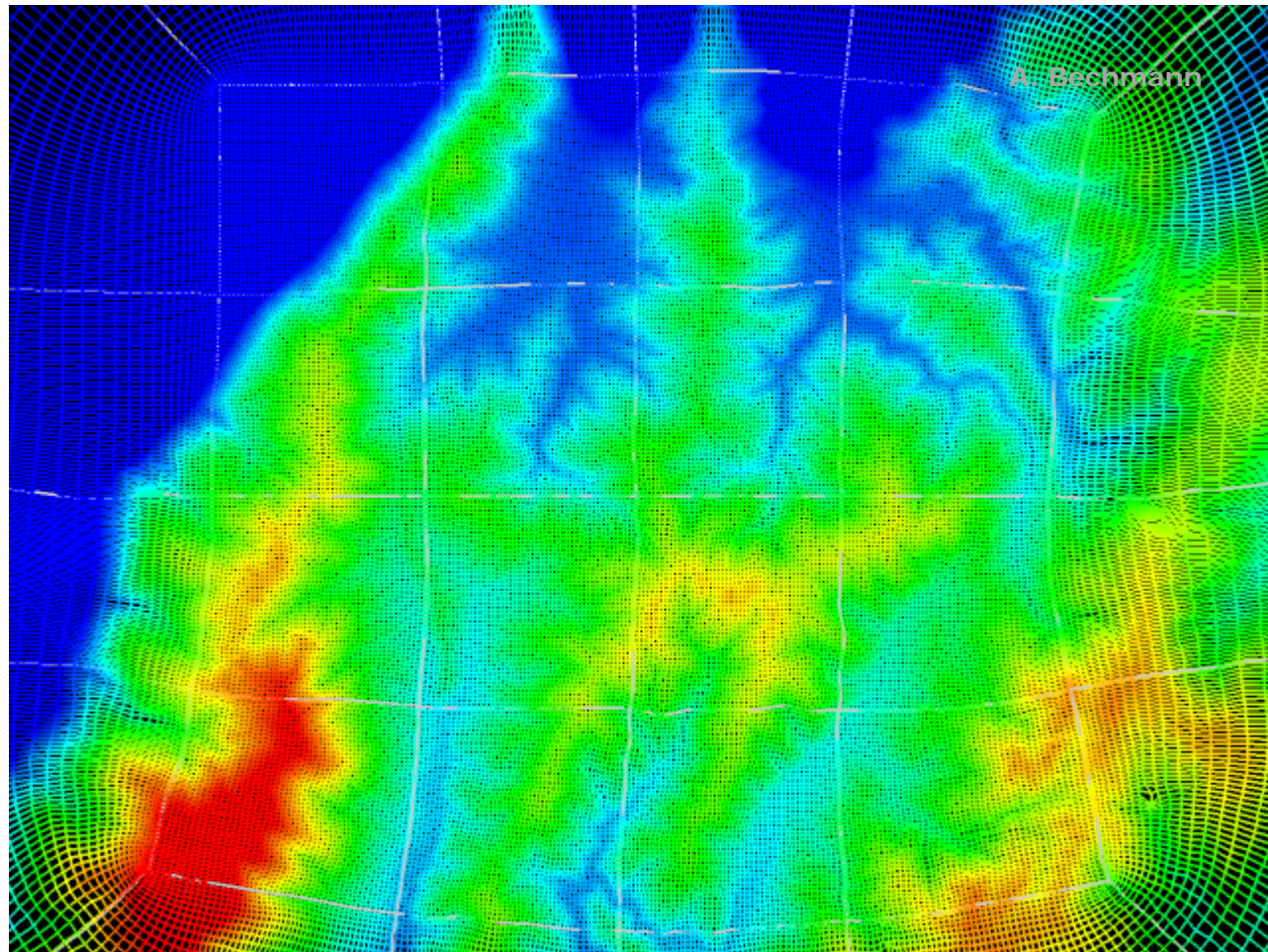
15km





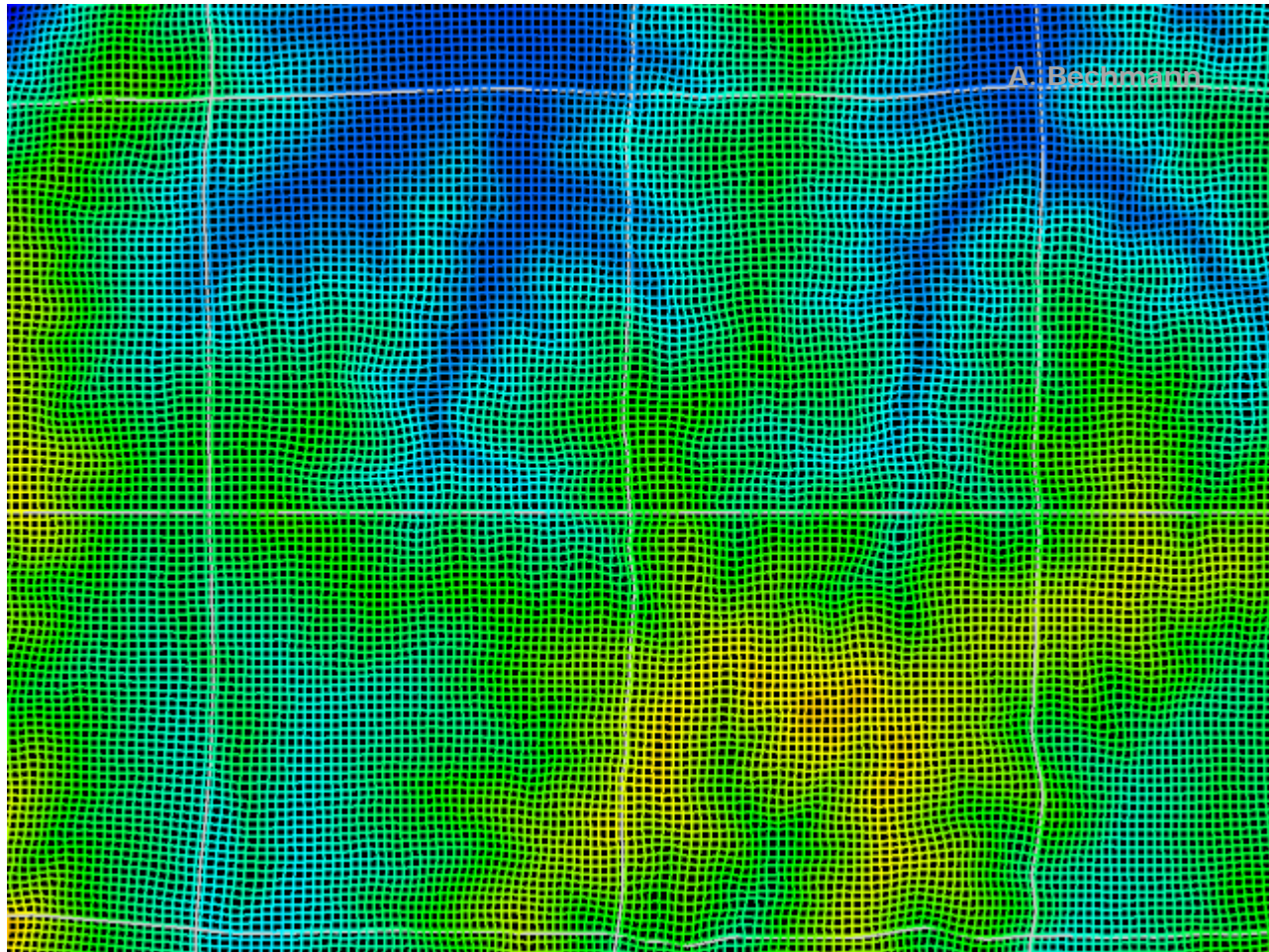
# Example: Mesh

6km



# Example: Mesh

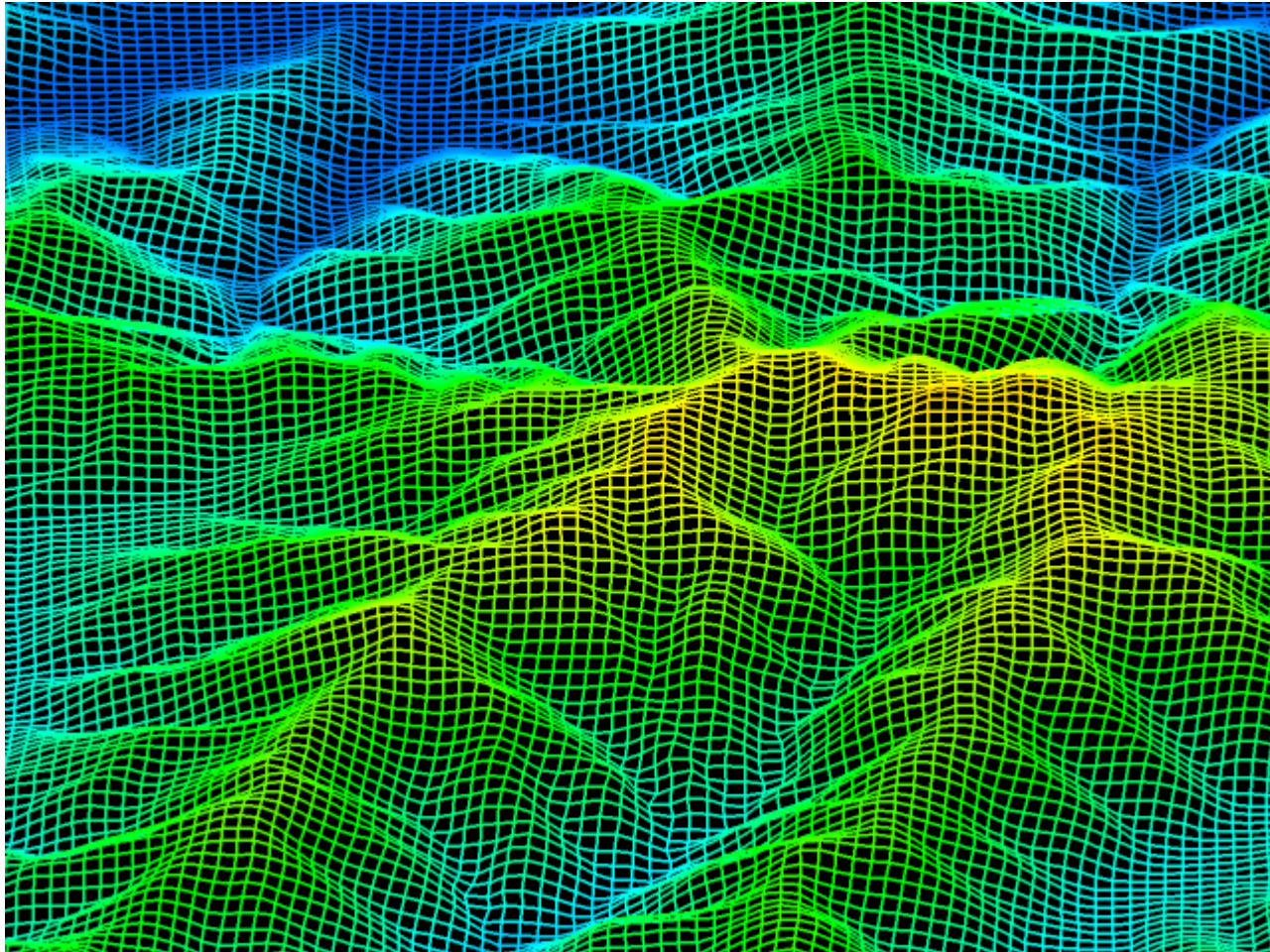
3km





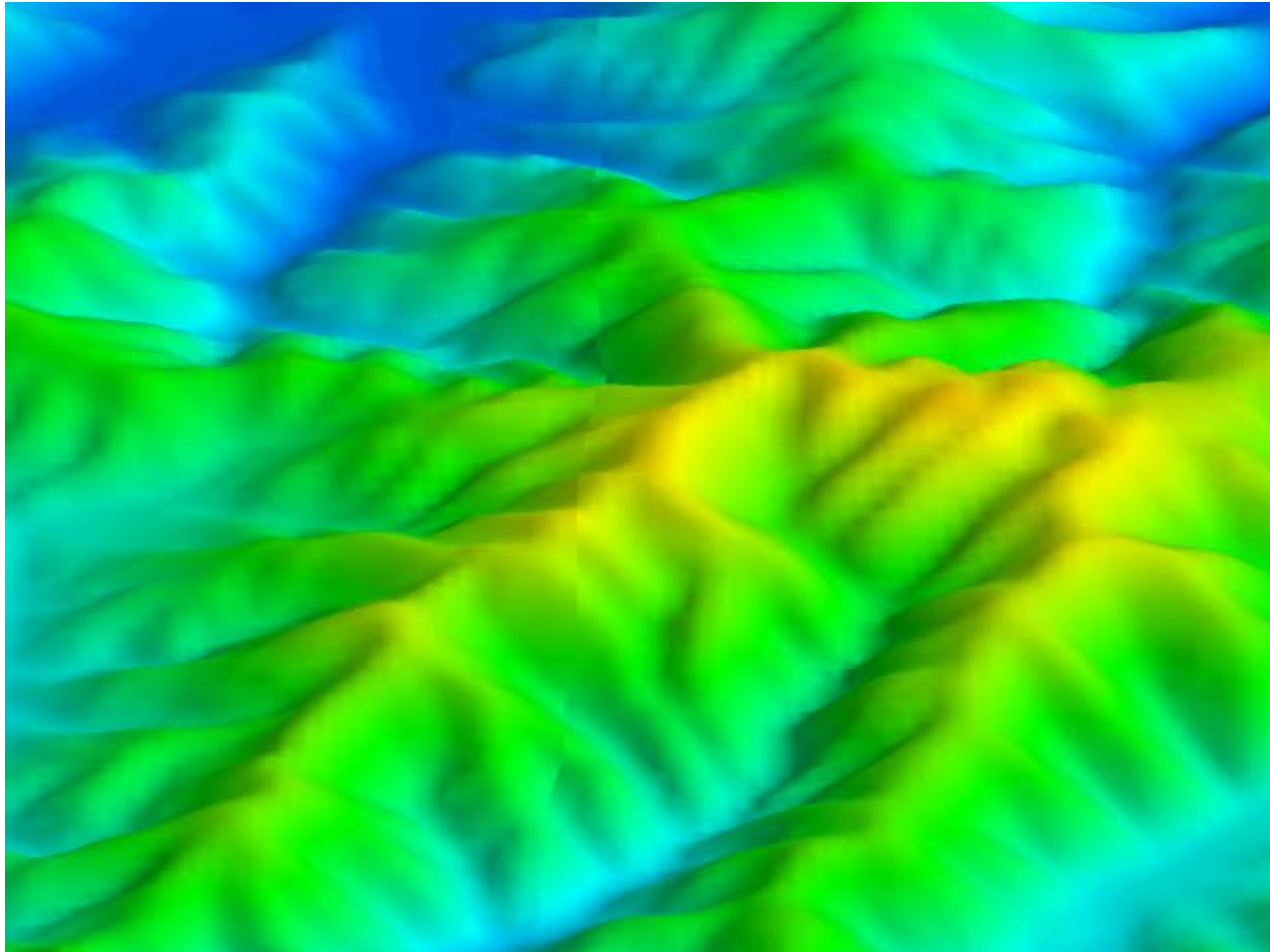
# Example: Mesh

*1km*



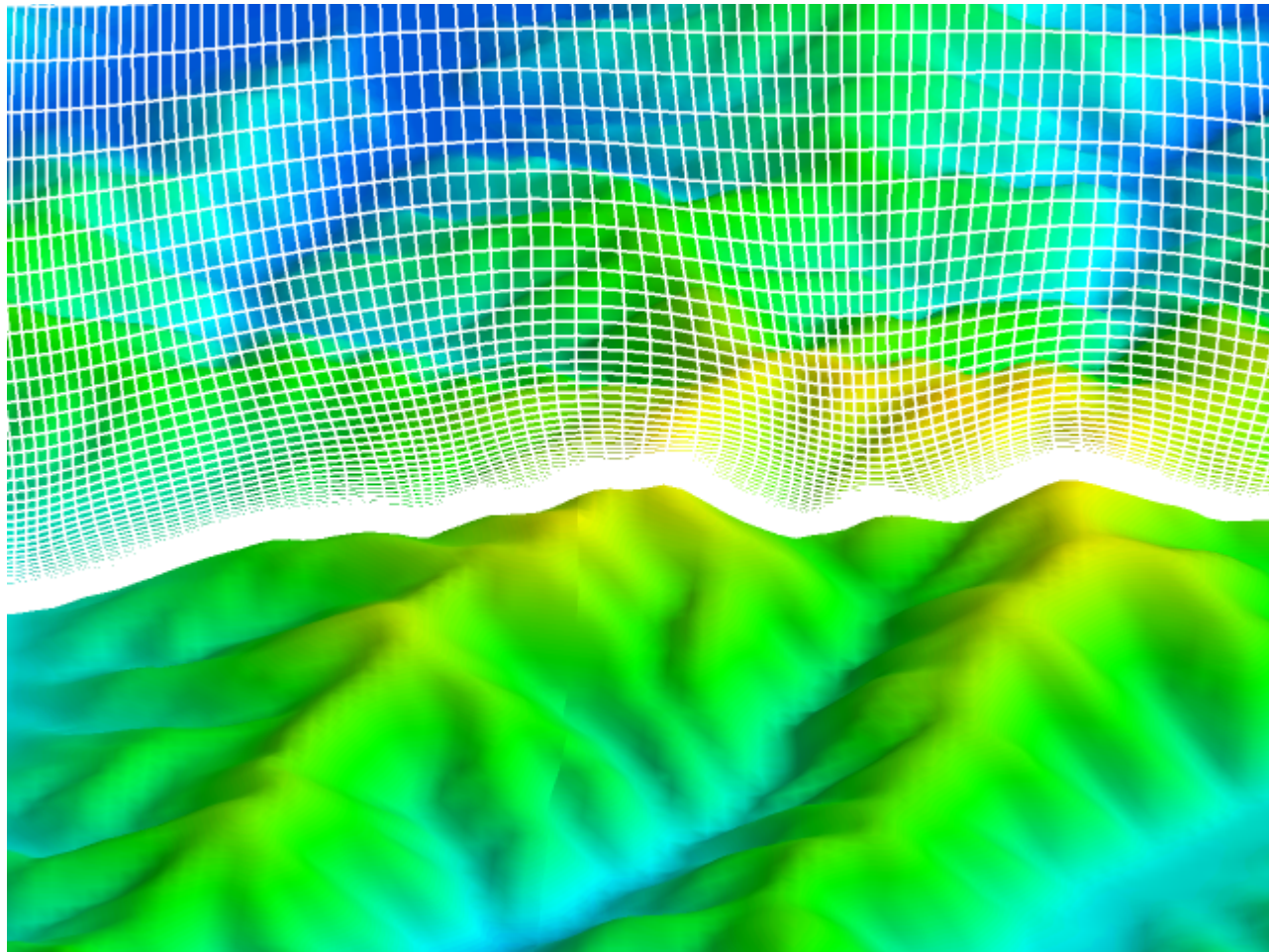
## Example: Mesh

*1km*



# Example: Mesh

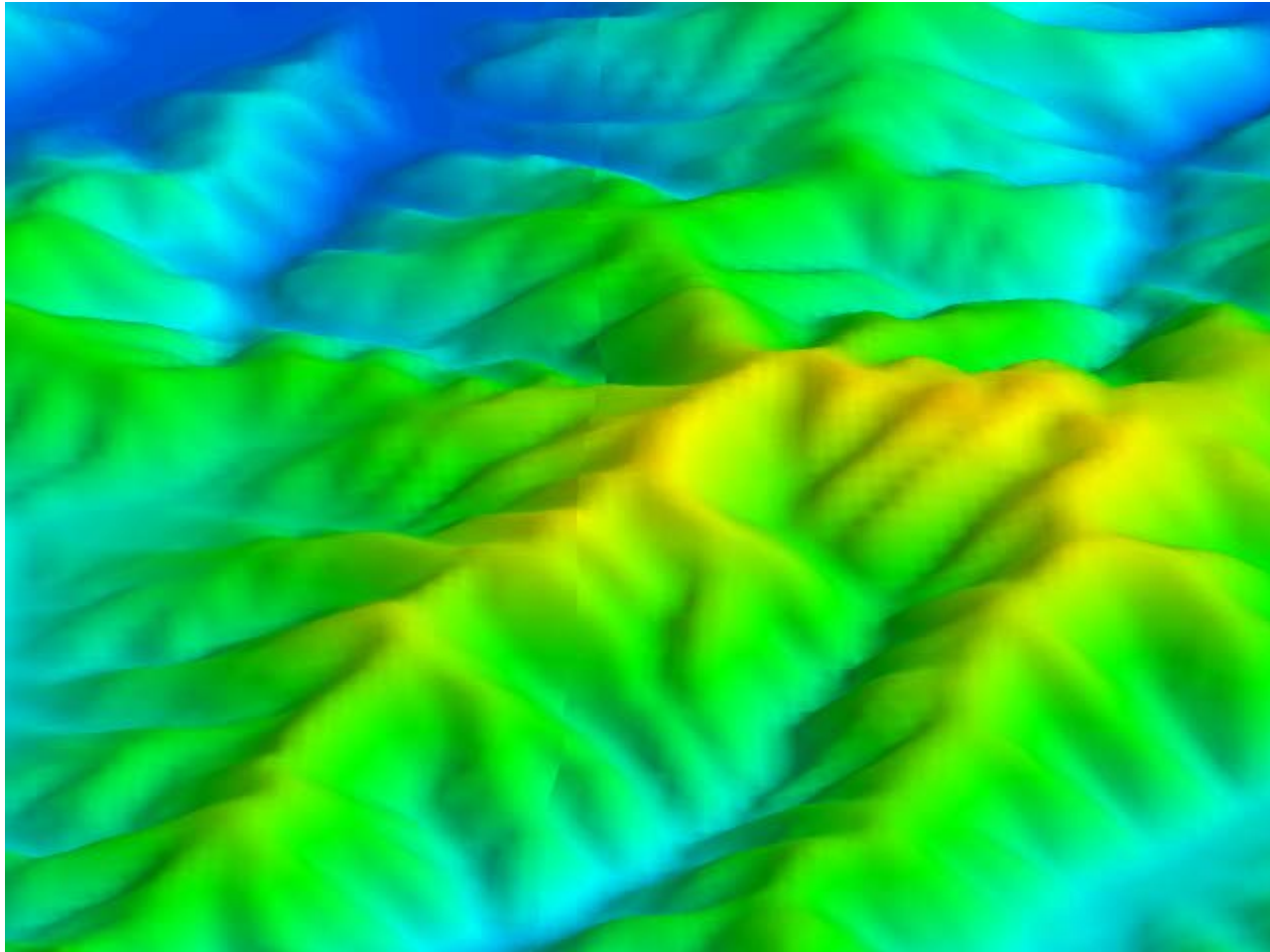
1km





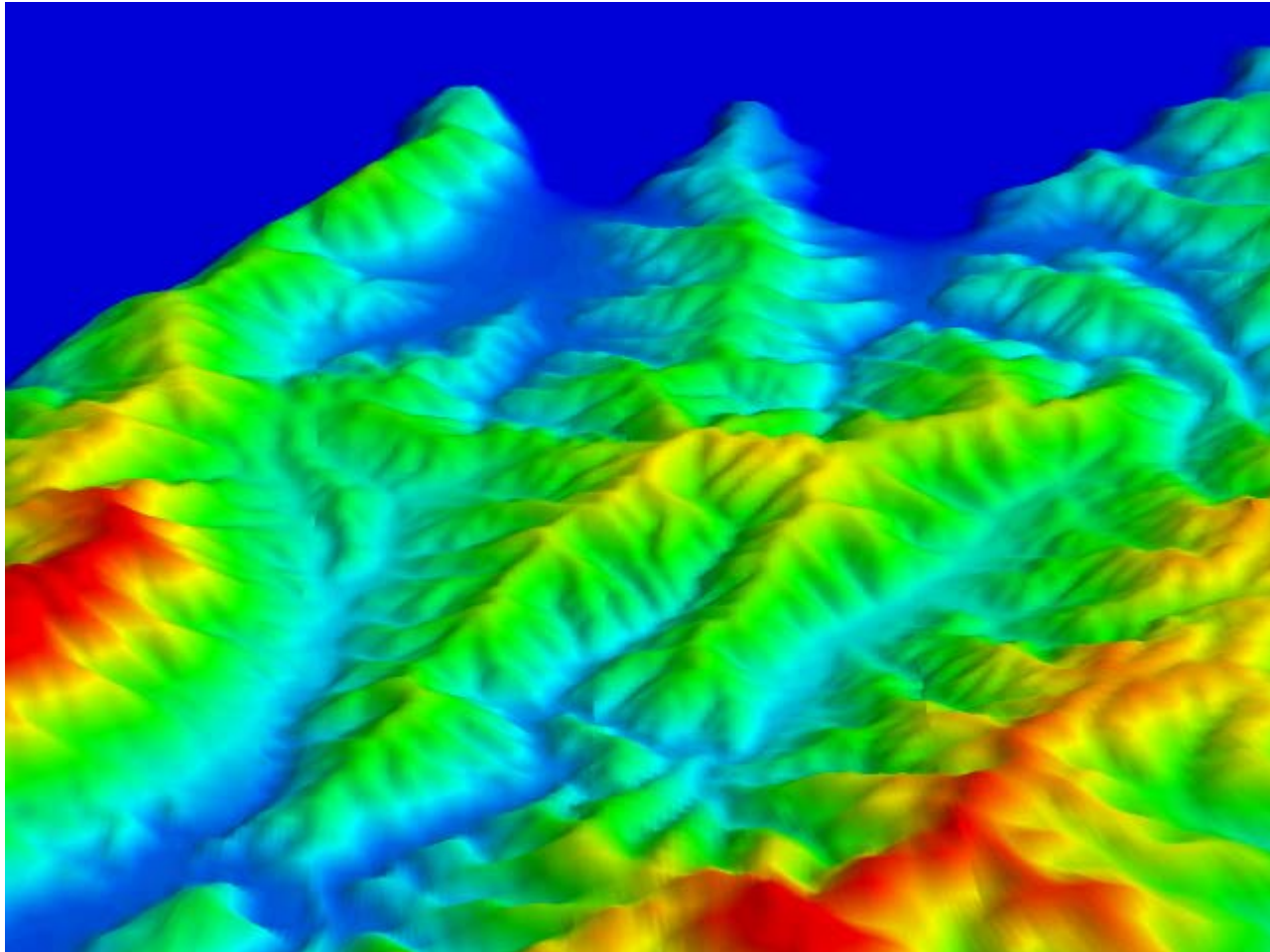
## Example: Mesh

*1km*



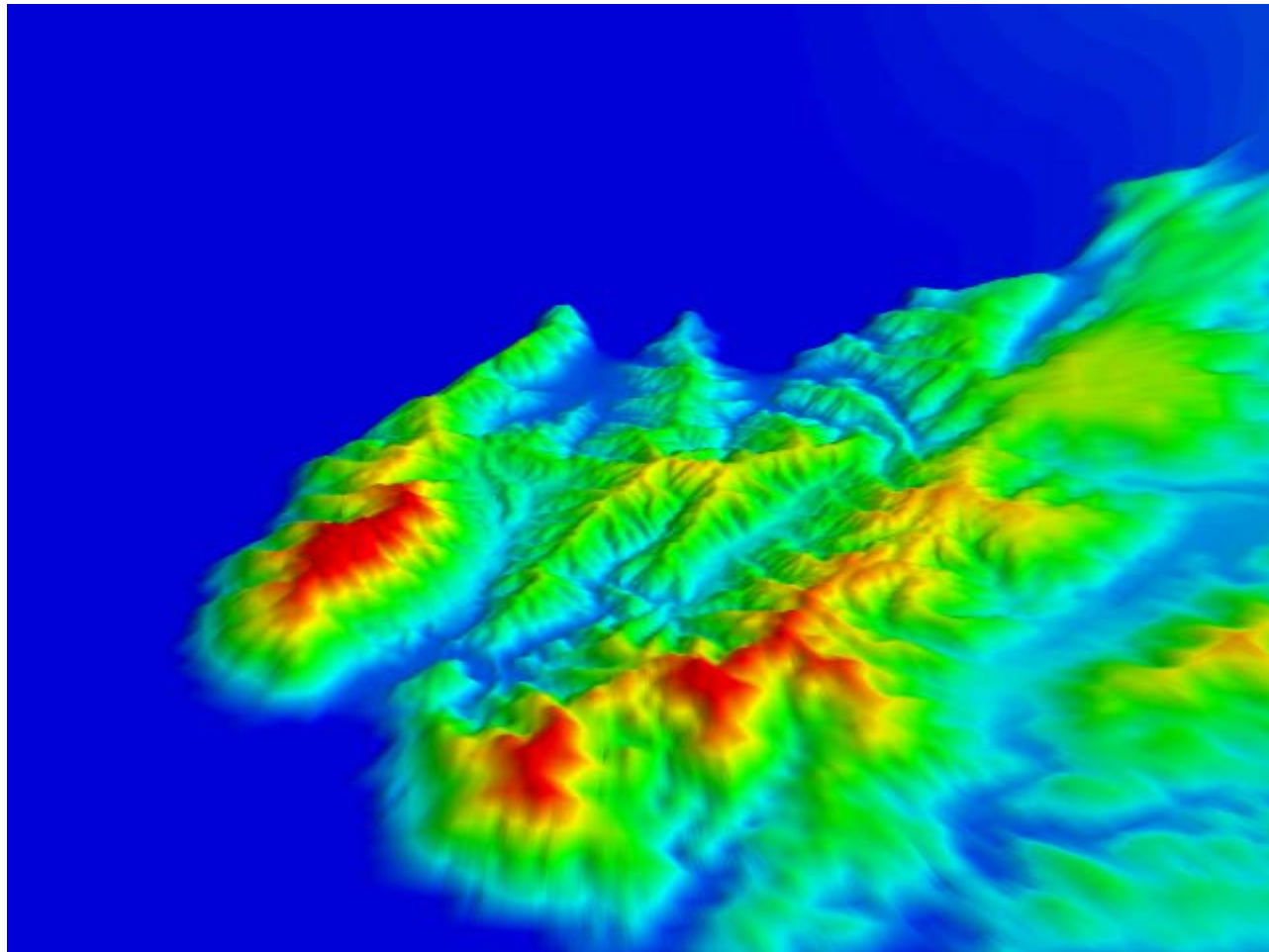
# Example: Mesh

*6km*



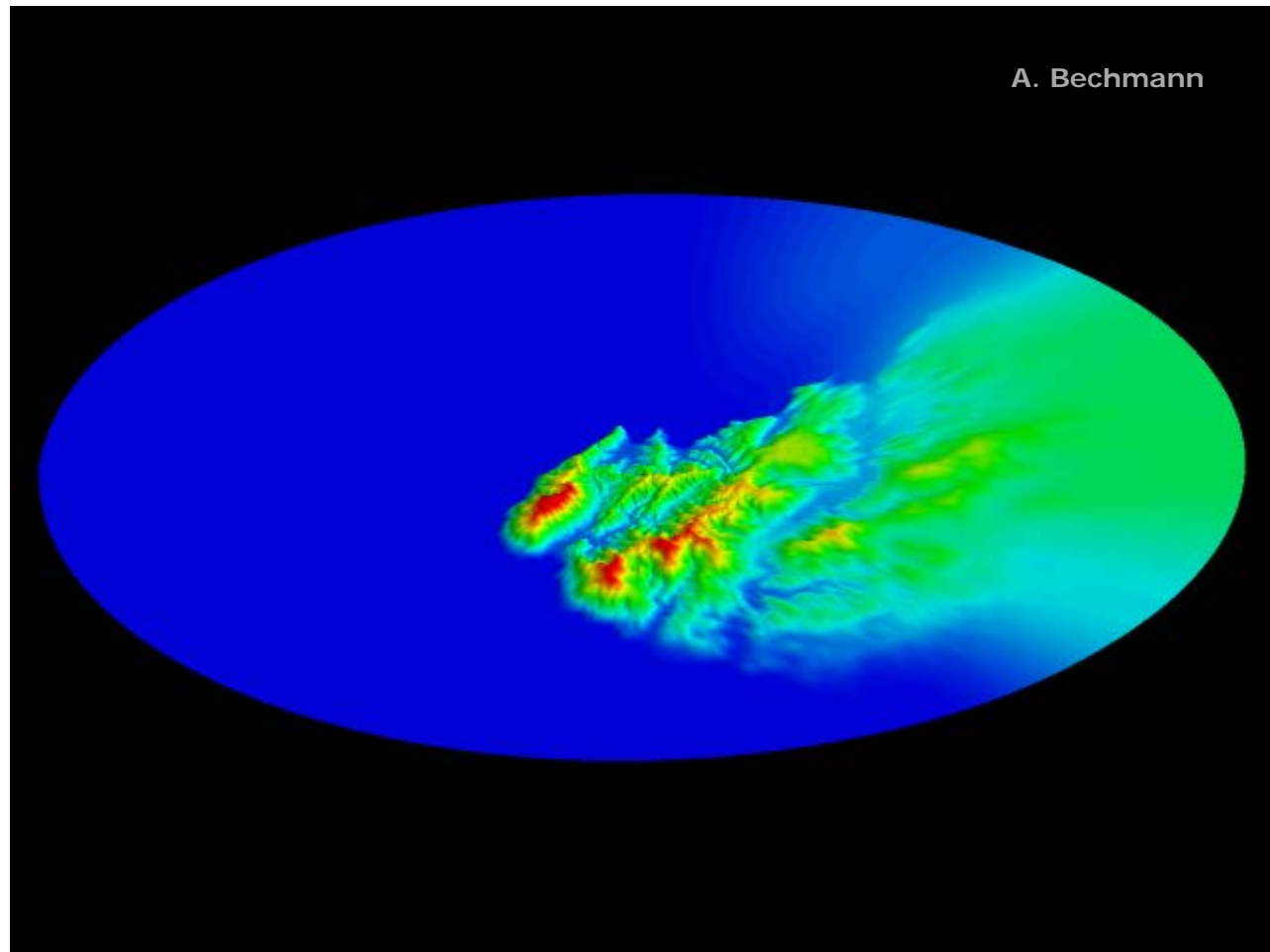
# Example: Mesh

15km



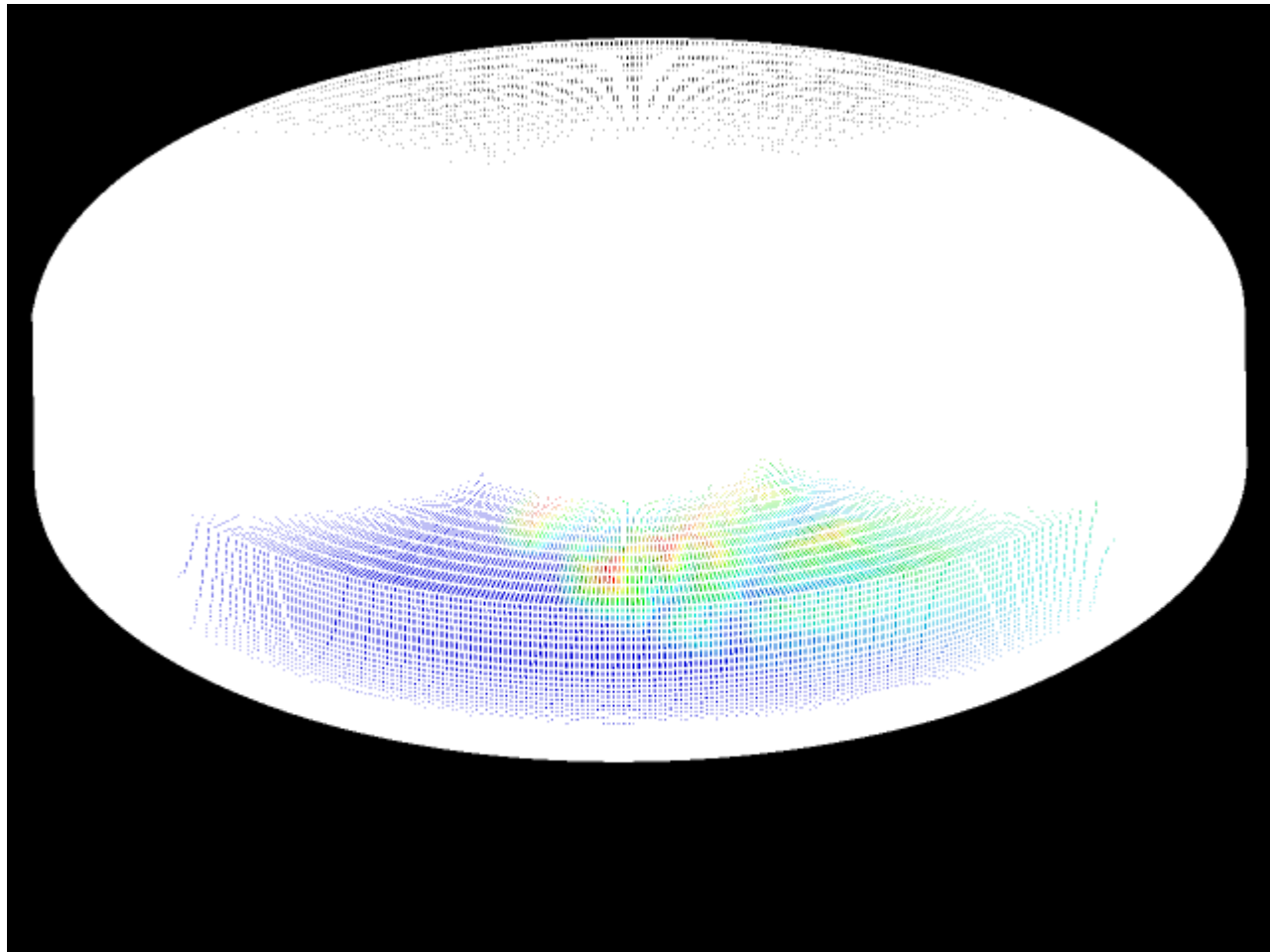
# Example: Mesh

34km



# Example: Mesh

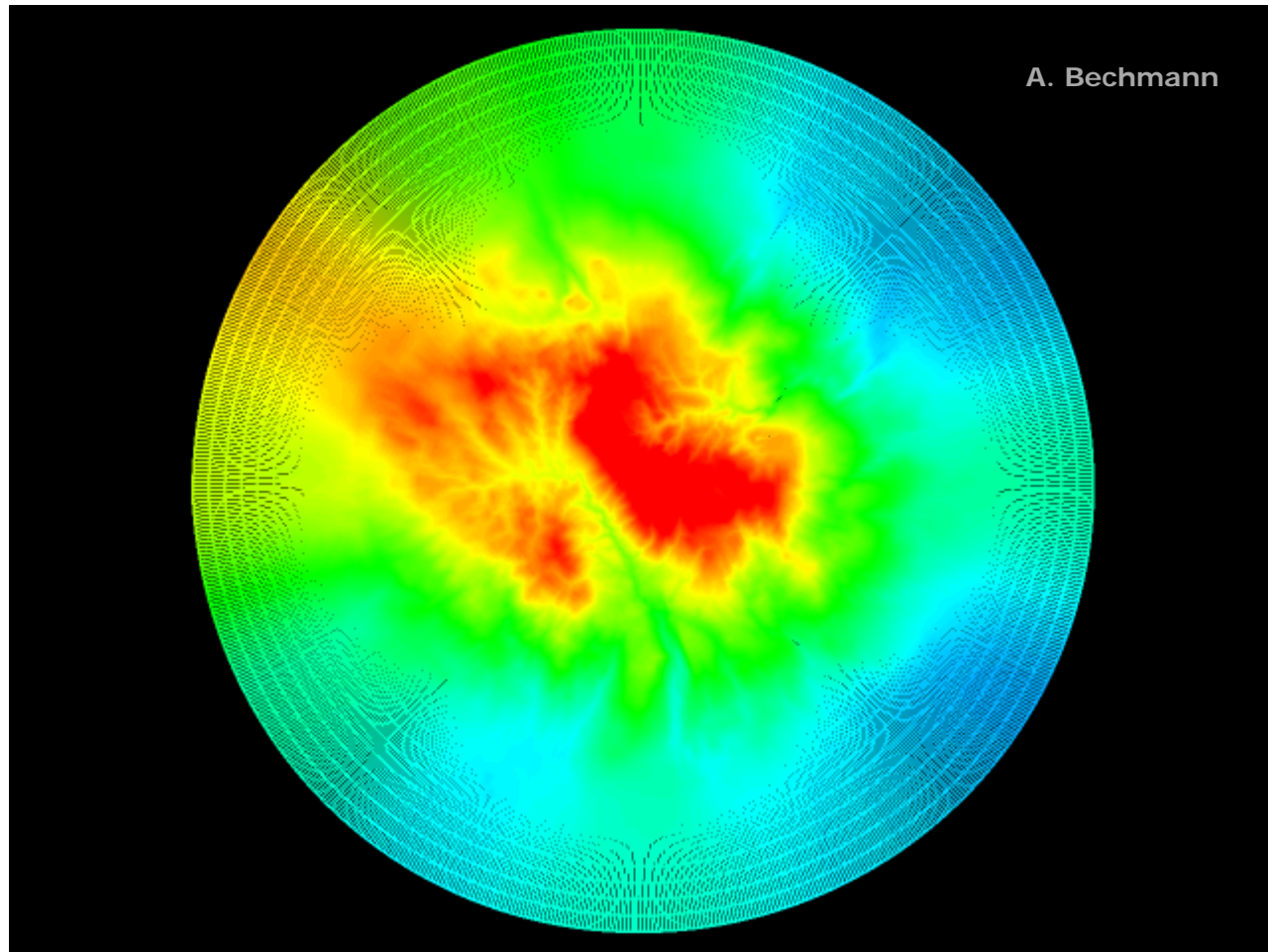
34km





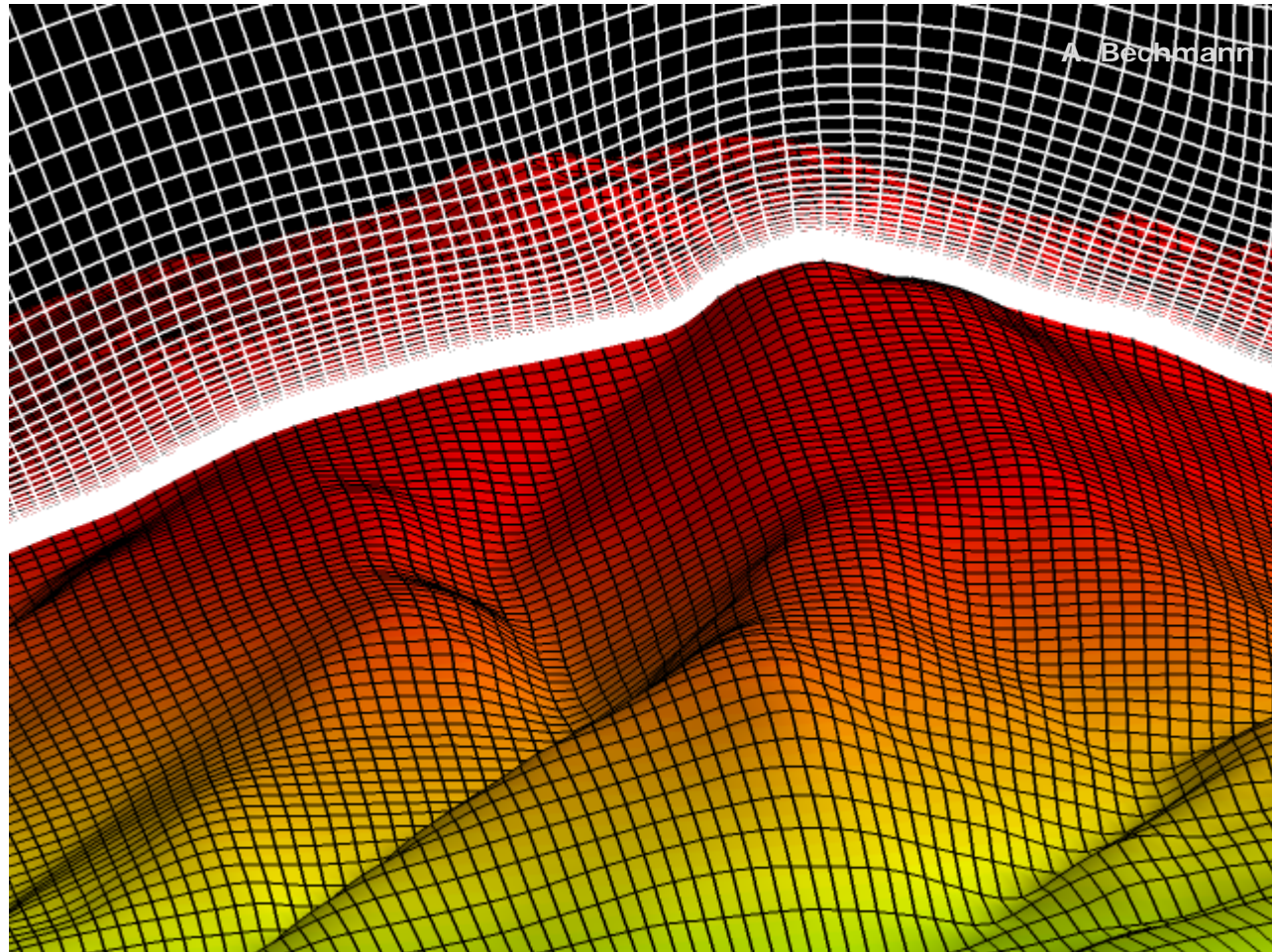
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34km



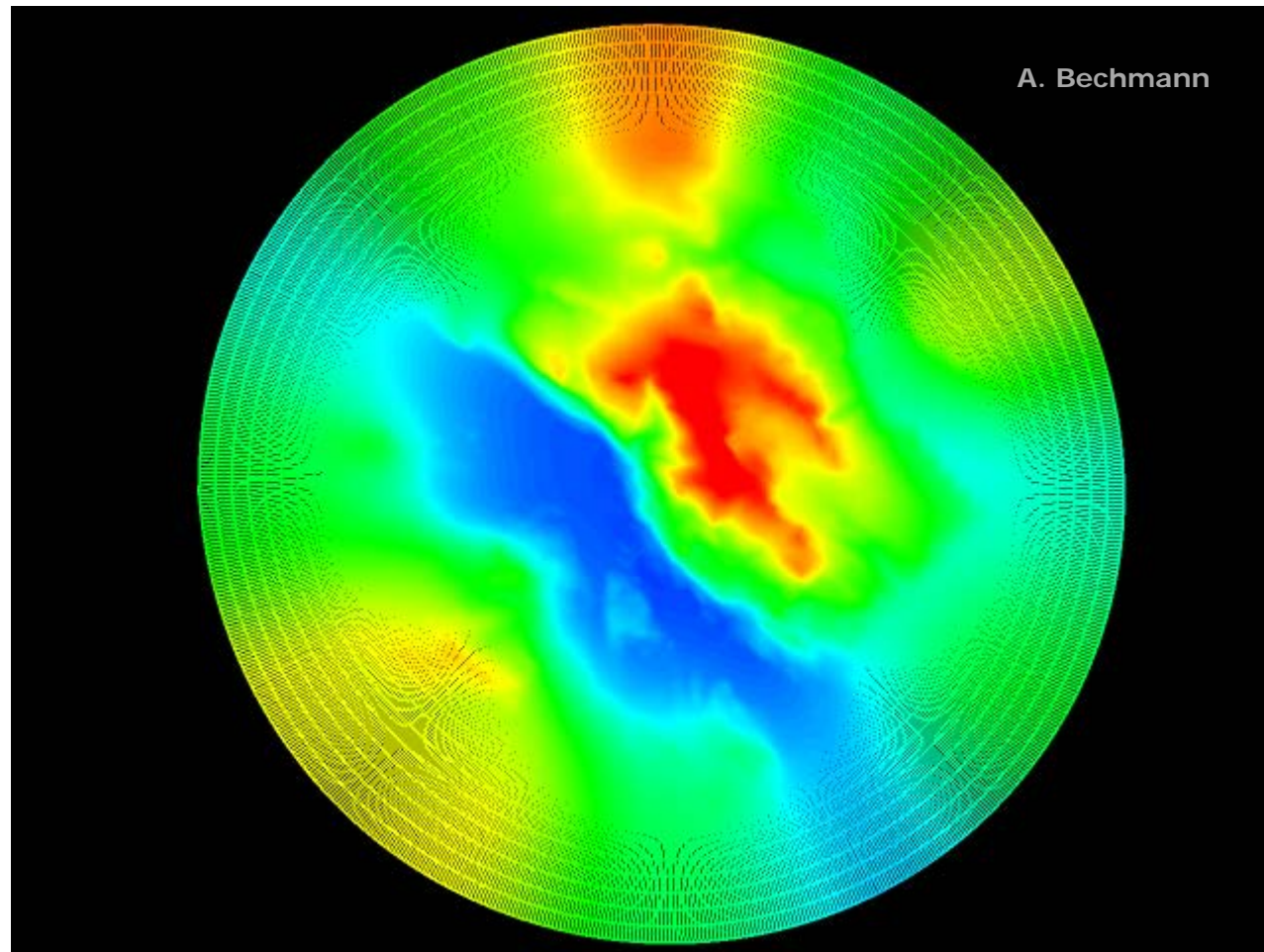
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1km



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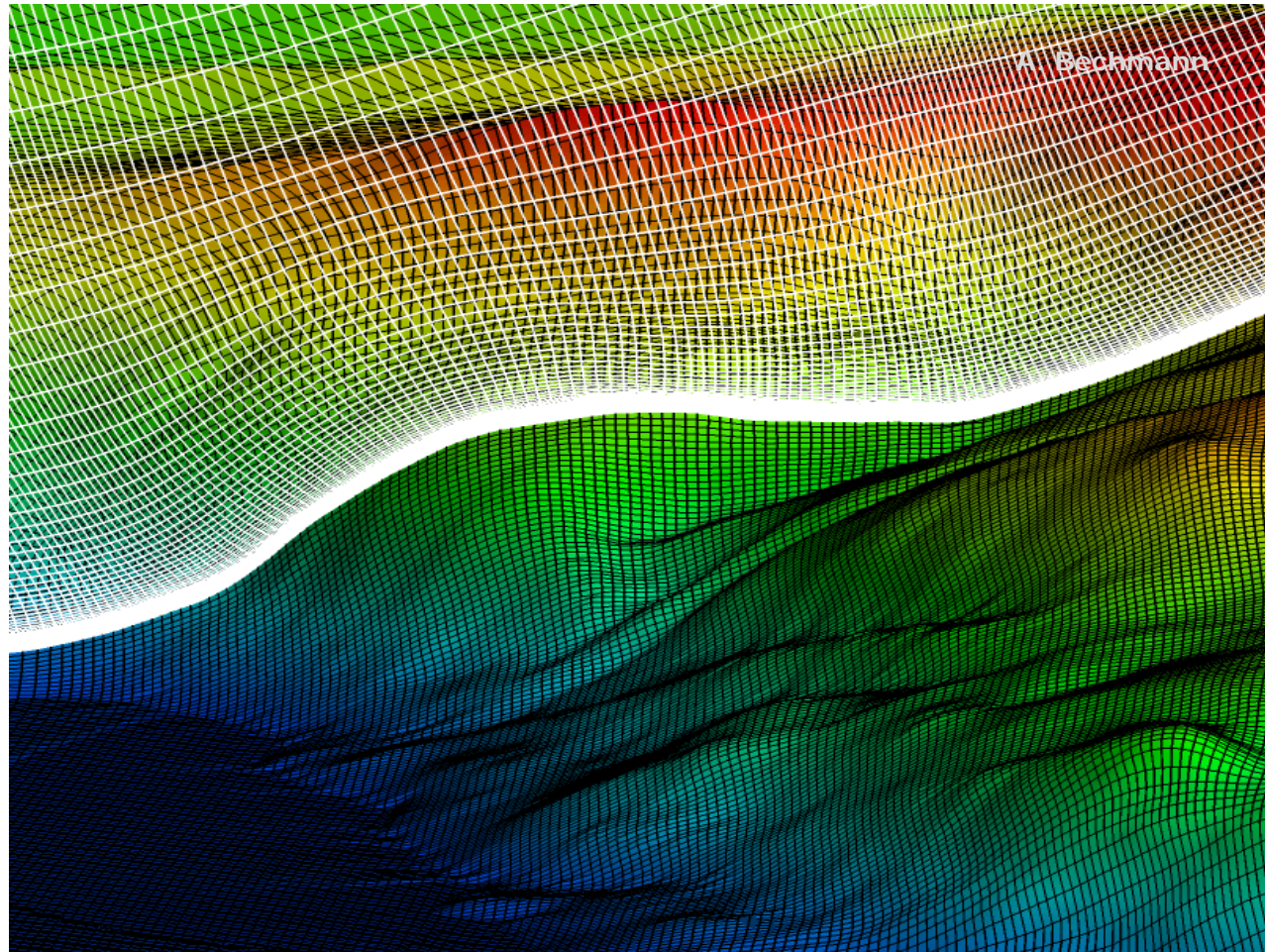
34km





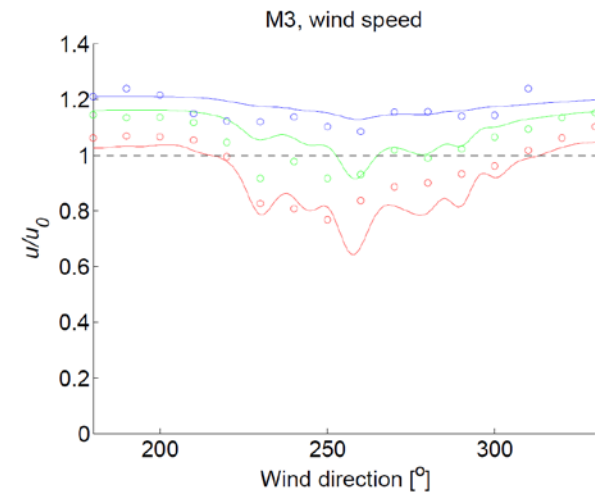
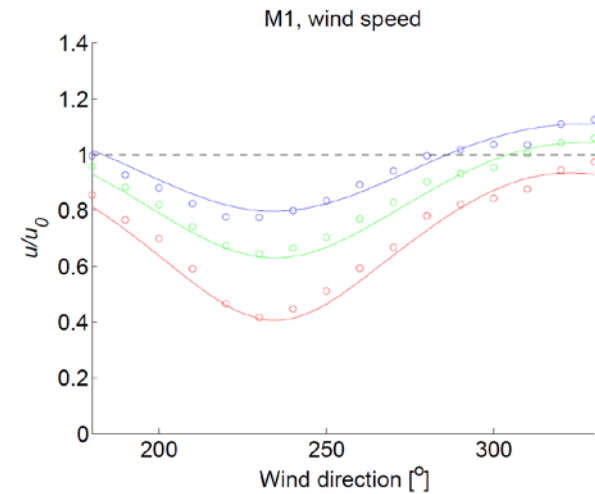
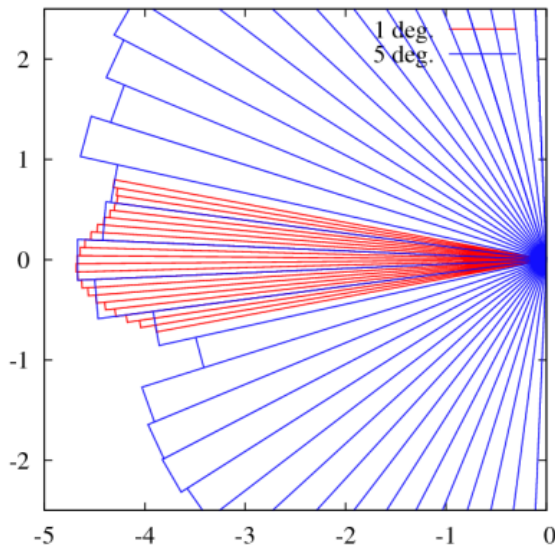
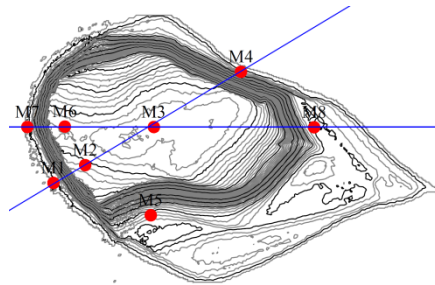
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1km

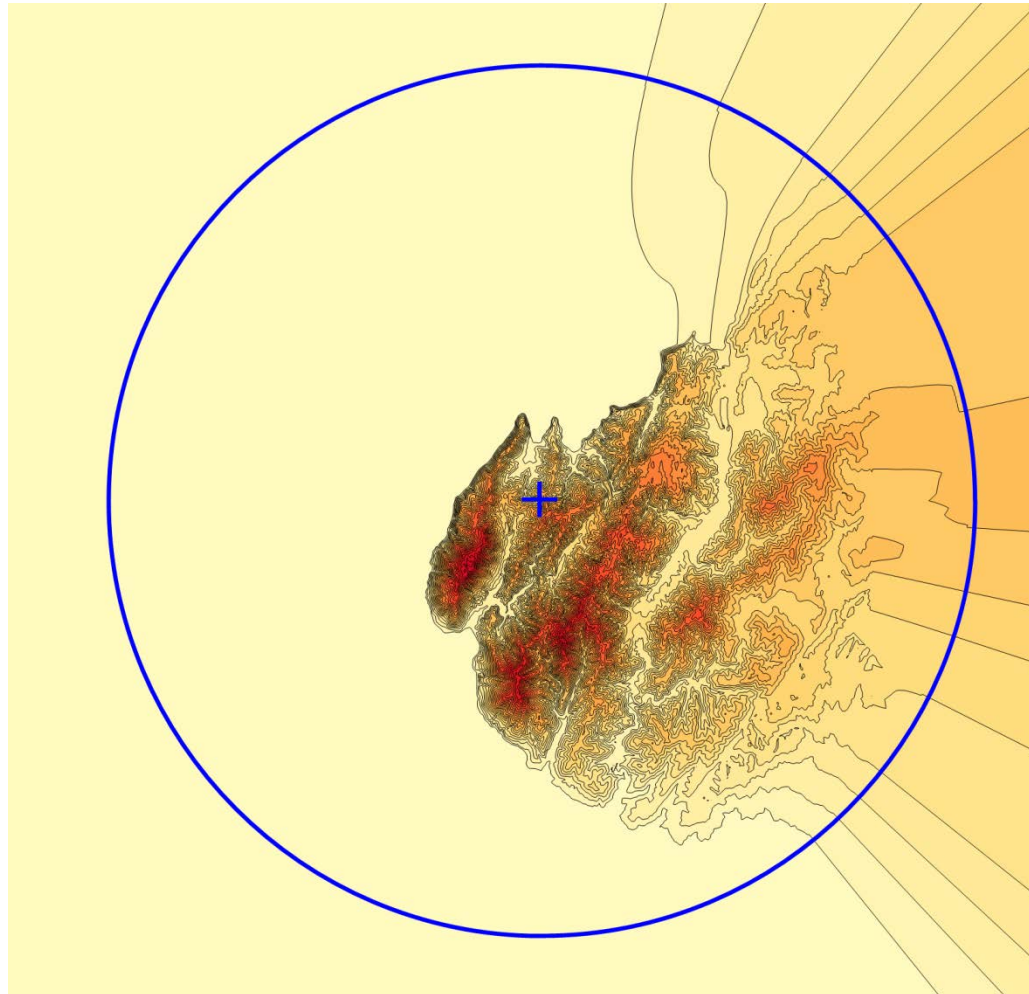


# Example: CFD

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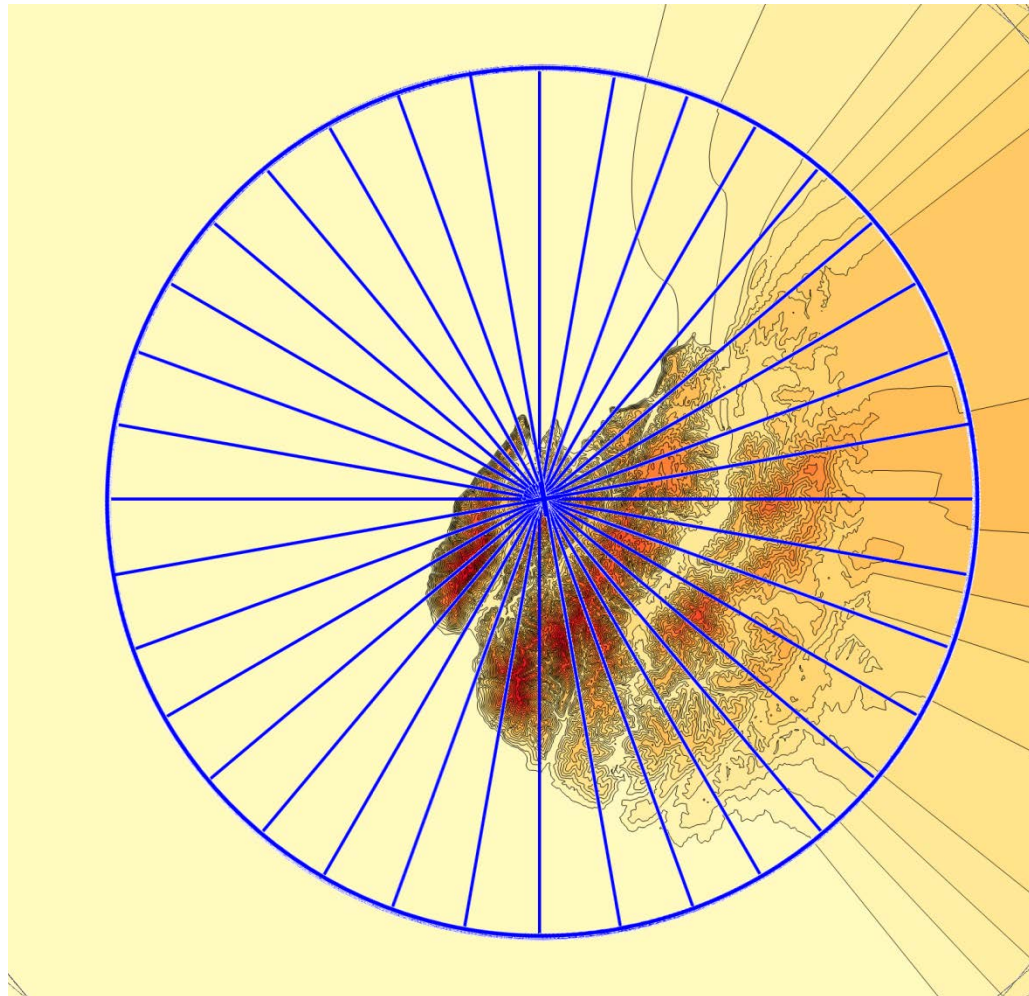


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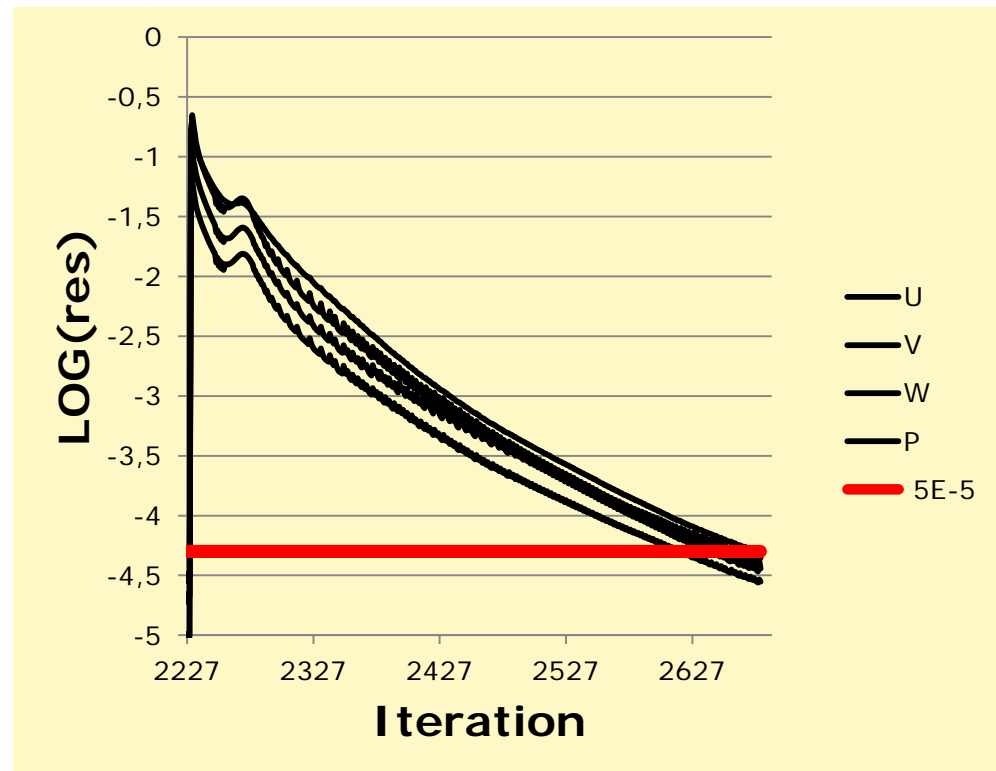


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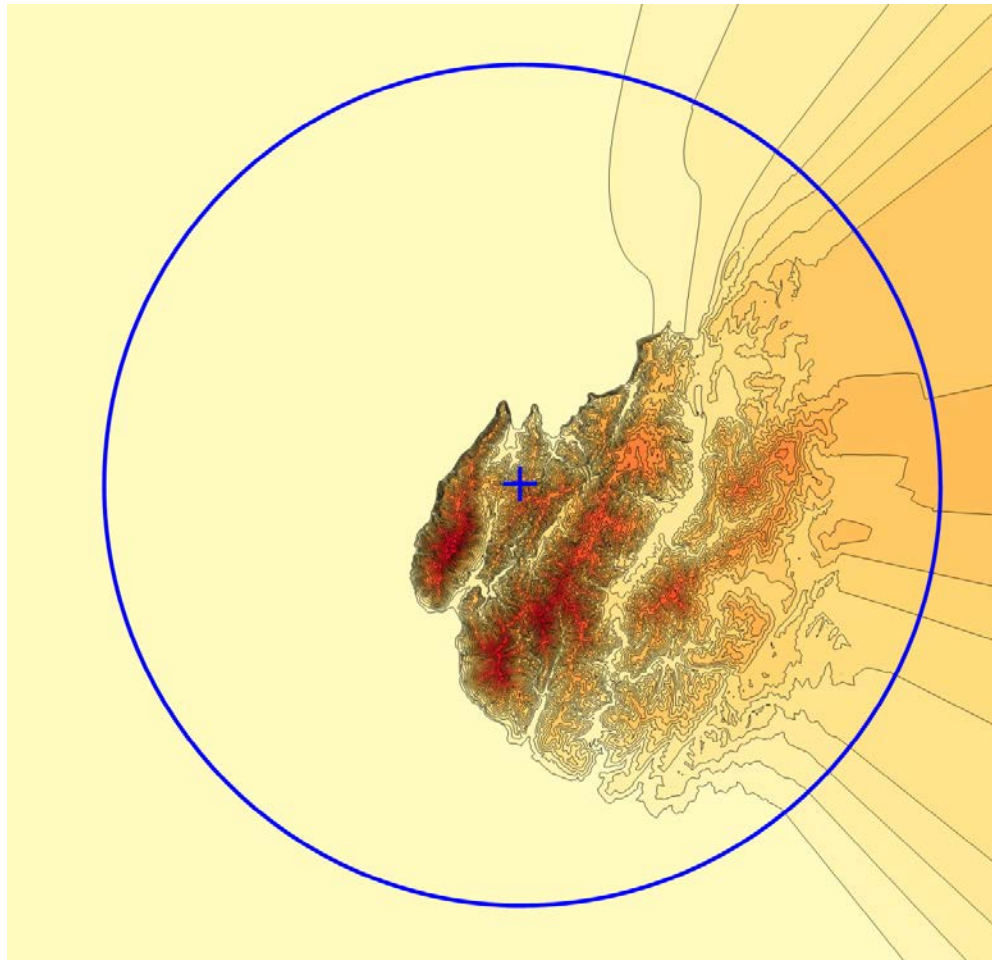


## Example: CFD

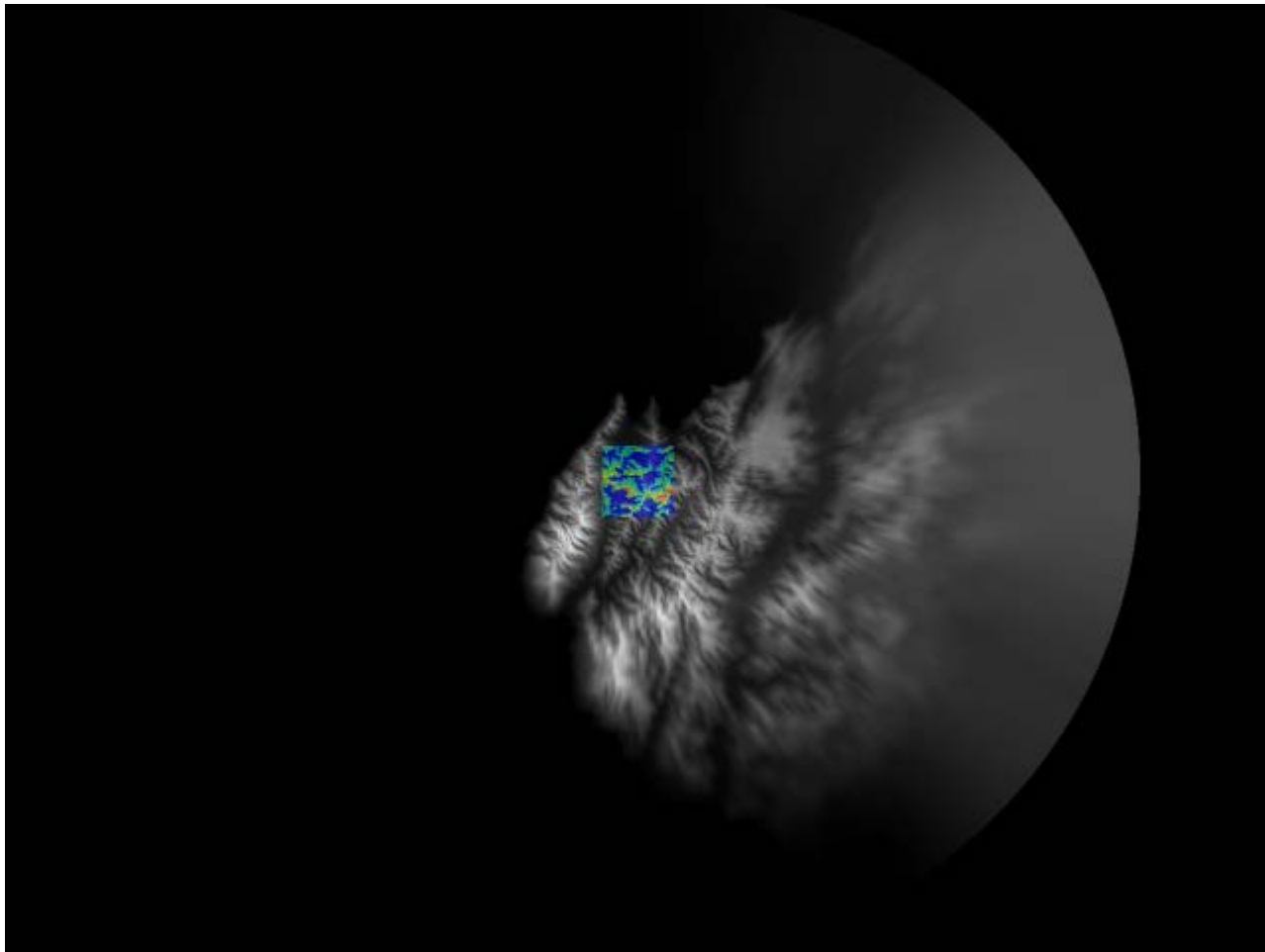
- Third order QUICK scheme
- RANS k- $\epsilon$  turbulence model
- Residuals < 5E-5



# Example: CFD

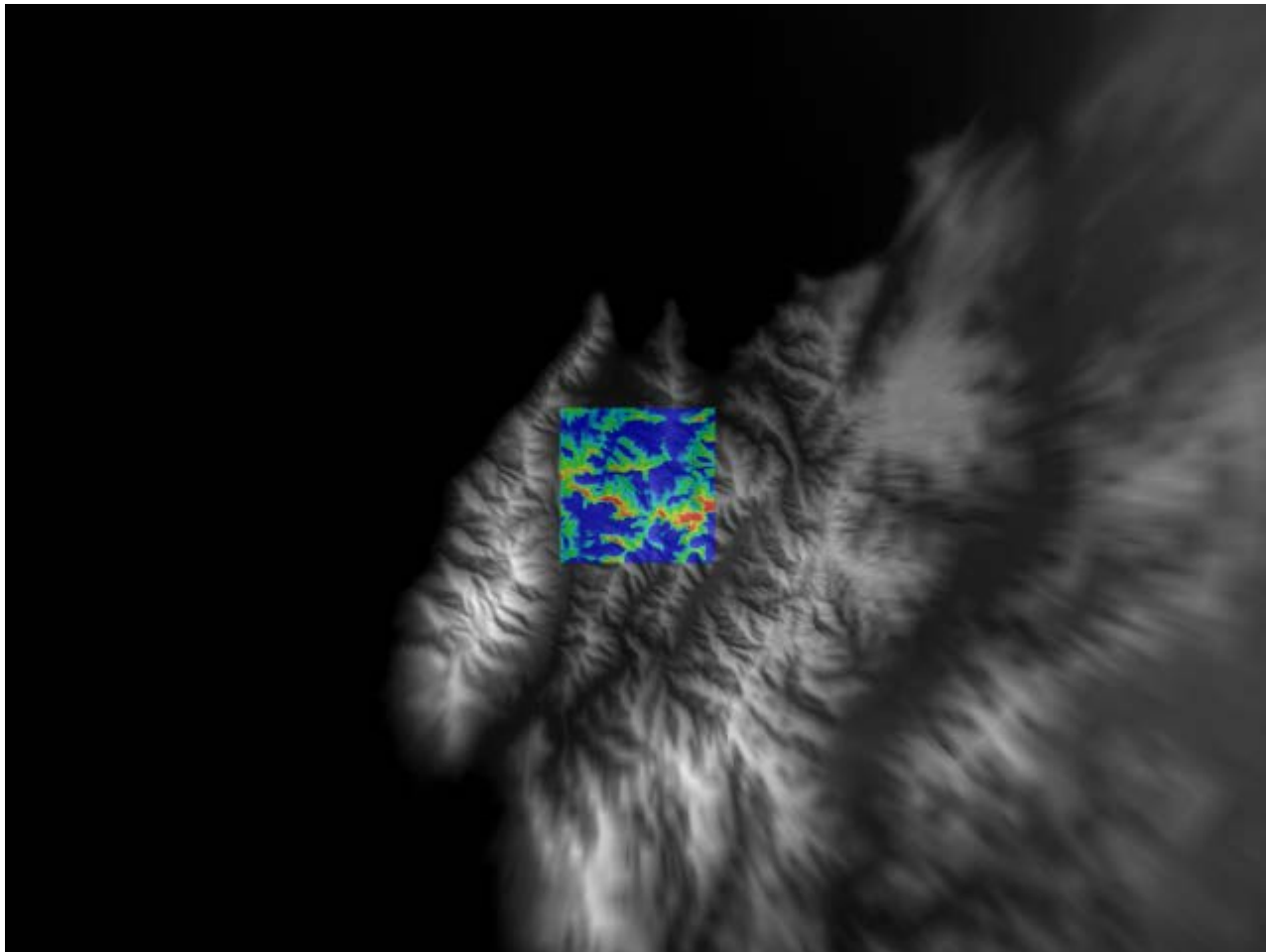


# Example: CFD

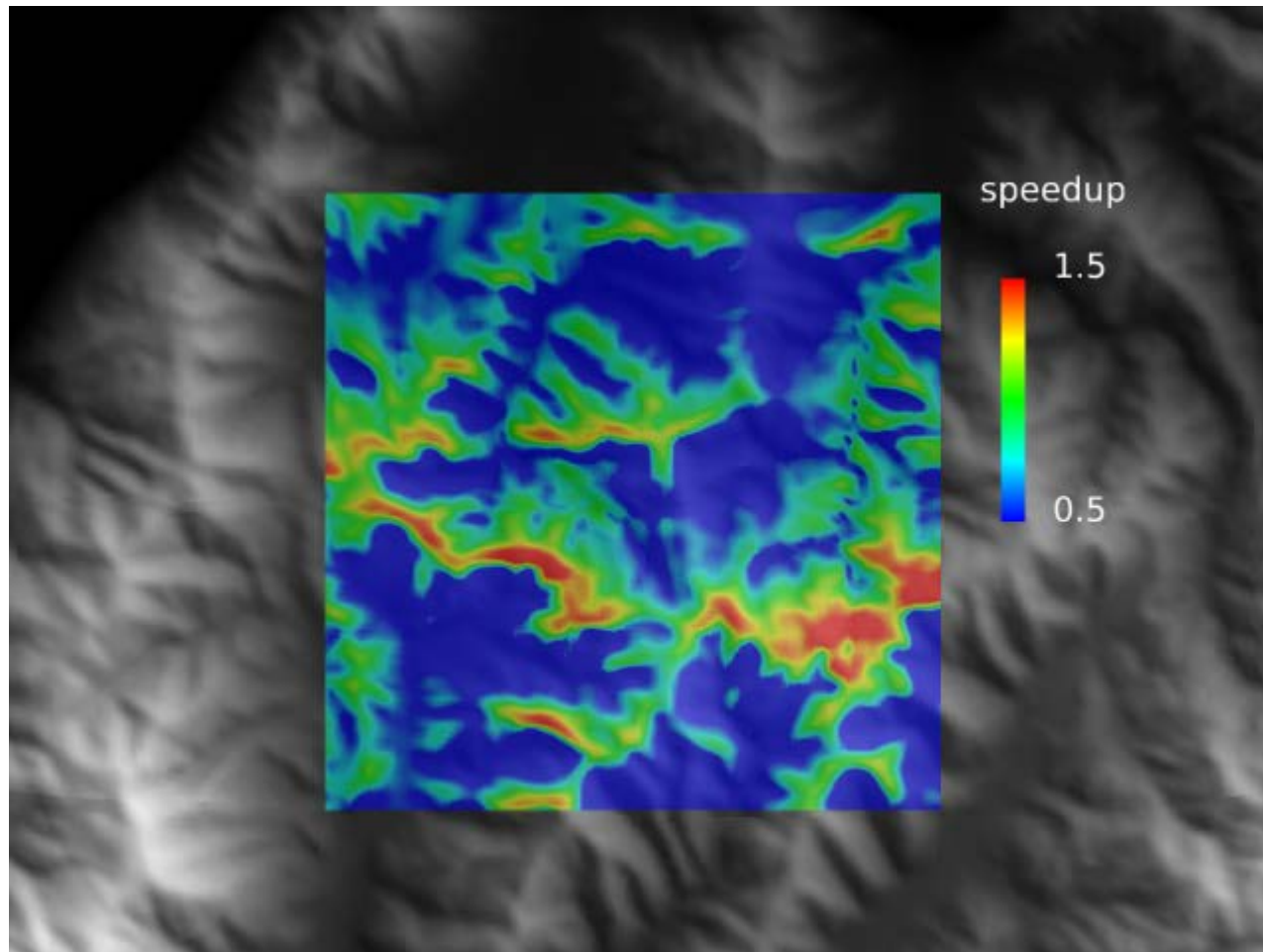




# Example: CFD

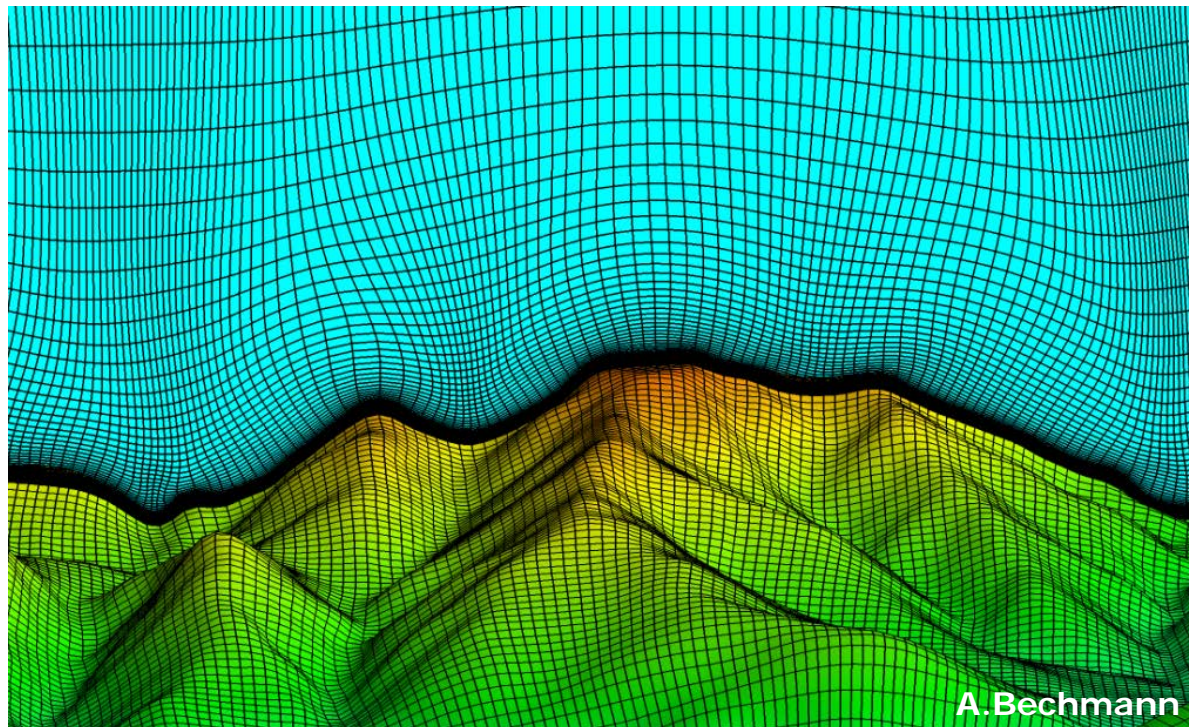


## Example: CFD



# How to use CFD for long-term energy assessments

1. Modelling of Wind Resources
2. Example: WAsP CFD
3. **Example: Forestry modeling based on aerial LIDAR scans**



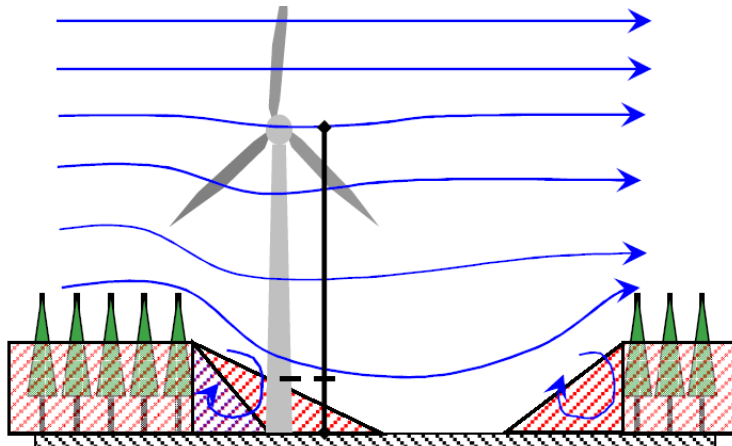
# Example: Forest

# Example: Forest

## Roughness length model

$$\bar{u} = \frac{u_*}{k} \ln \left( \frac{z-d}{z_0} \right)$$

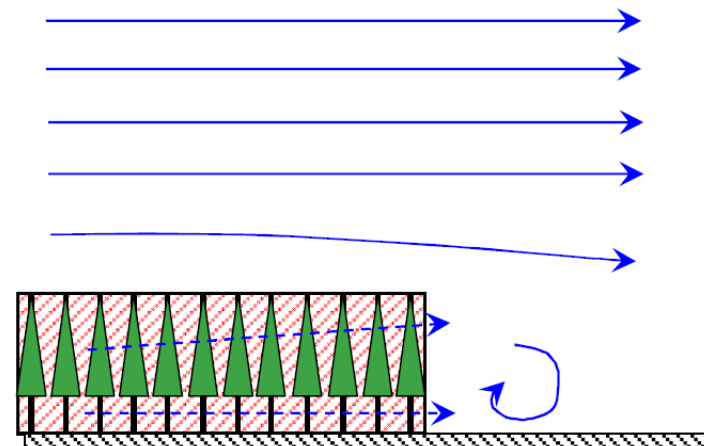
- $z_0$ : roughness length
- $d$ : displacement height



## Porous drag model

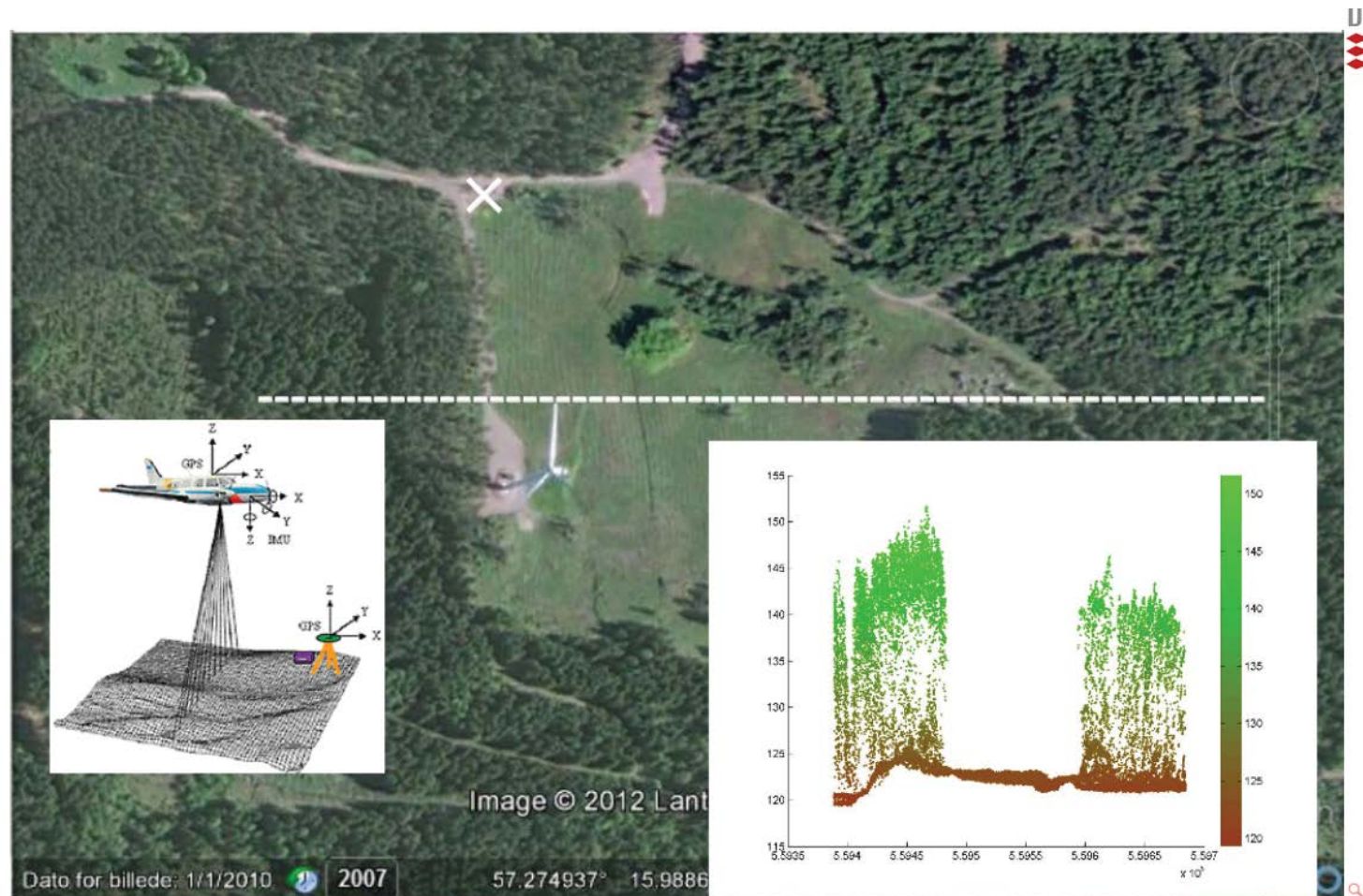
$$\frac{\partial u_i}{\partial t} = \dots - C_d LAD(z) u_i |U|$$

- LAD: leaf area density
- $C_d$ : drag coefficient



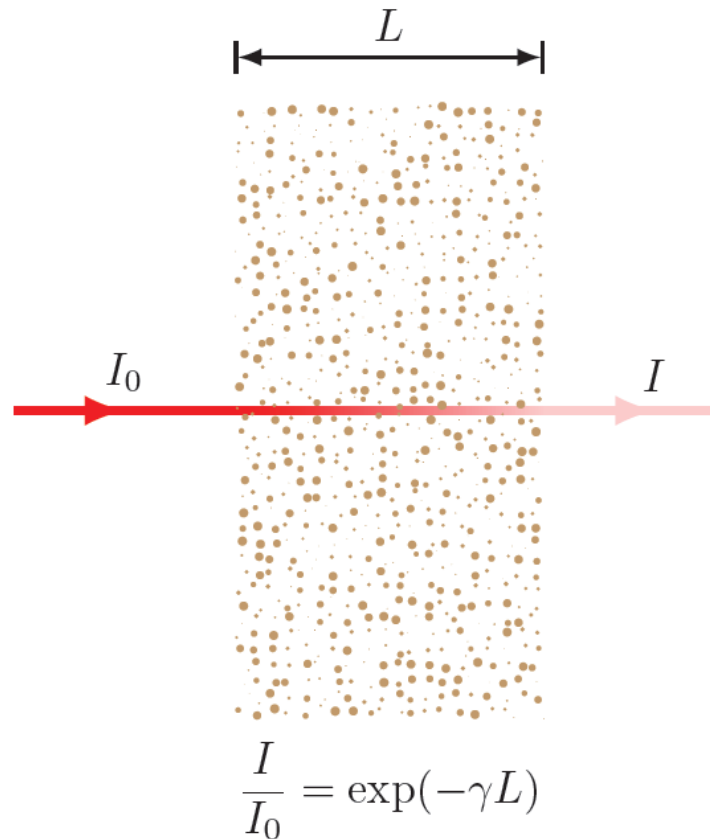


# Example: Forest



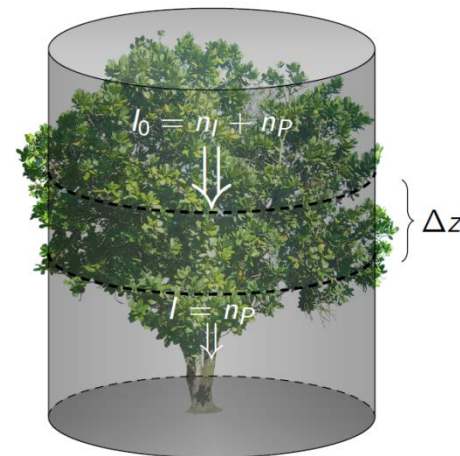
# Example: Forest

## The Beer-Lambert law



Light attenuation in plant canopies:  
[Monsi and Saeki, 2005]

$$LAI = -\frac{1}{\gamma} \ln \left( \frac{I}{I_0} \right)$$



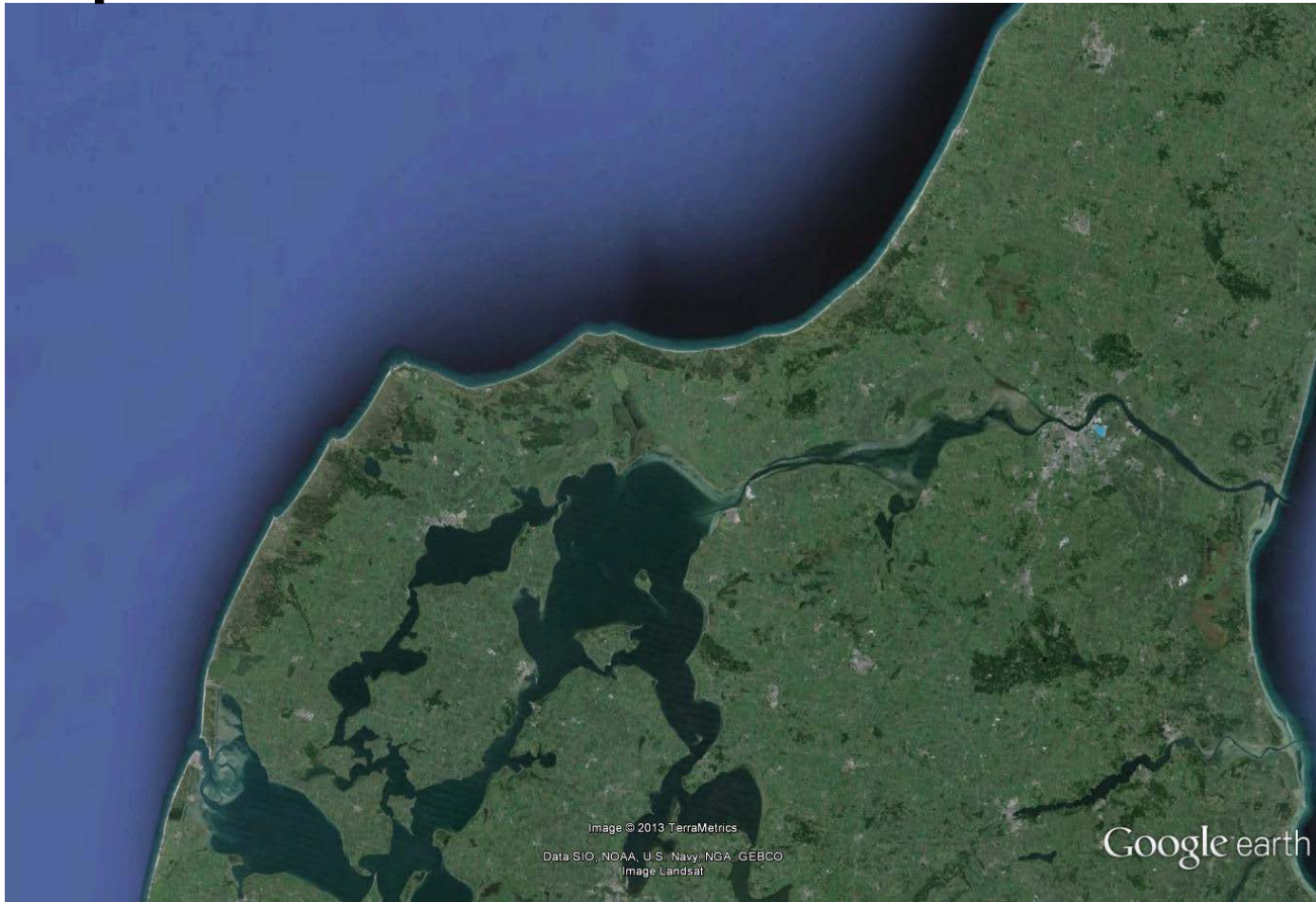
$$LAI = \int_0^z LAD \, dz \Rightarrow LAD = \frac{dLAI}{dz}$$

# Example: Forest

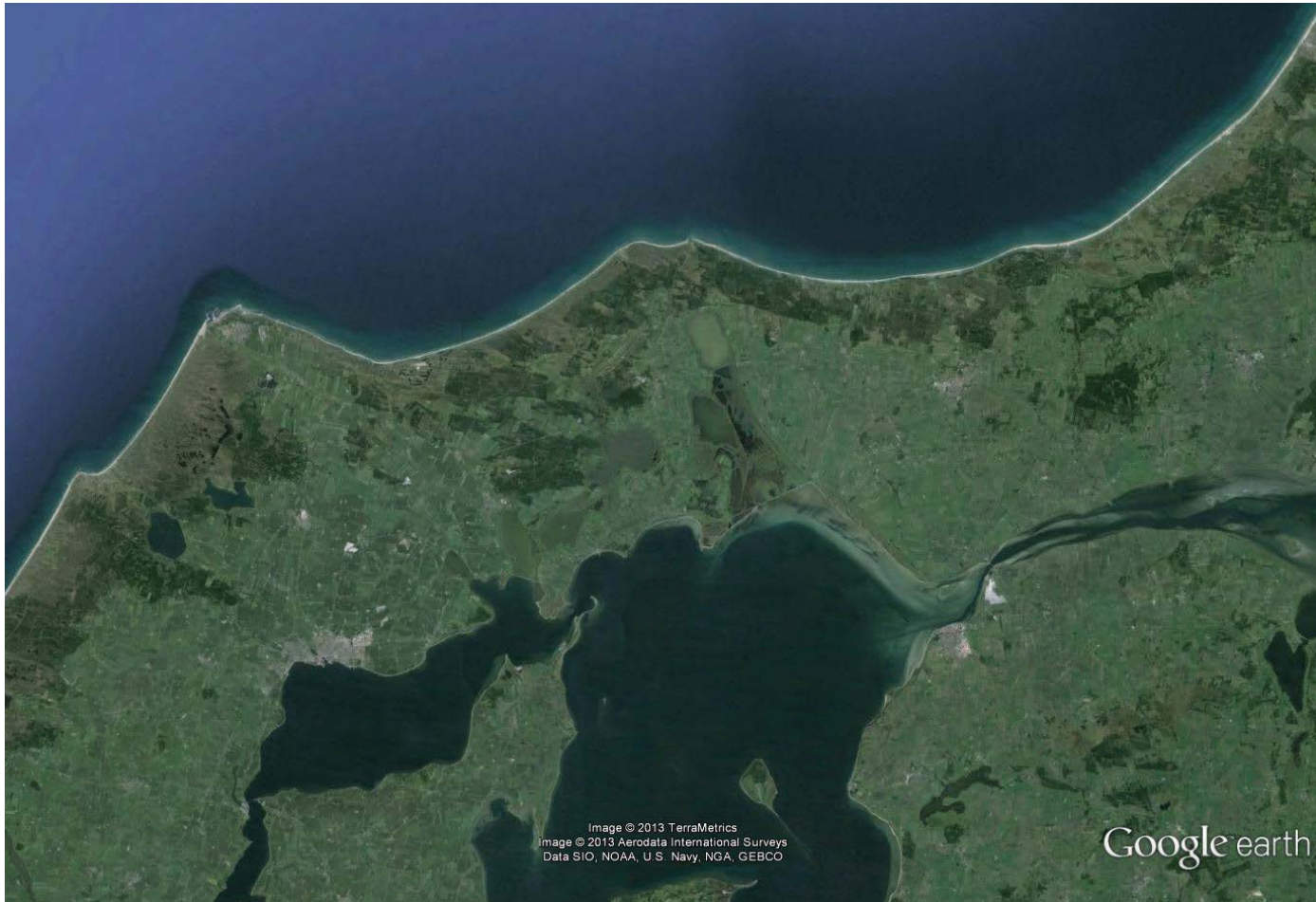




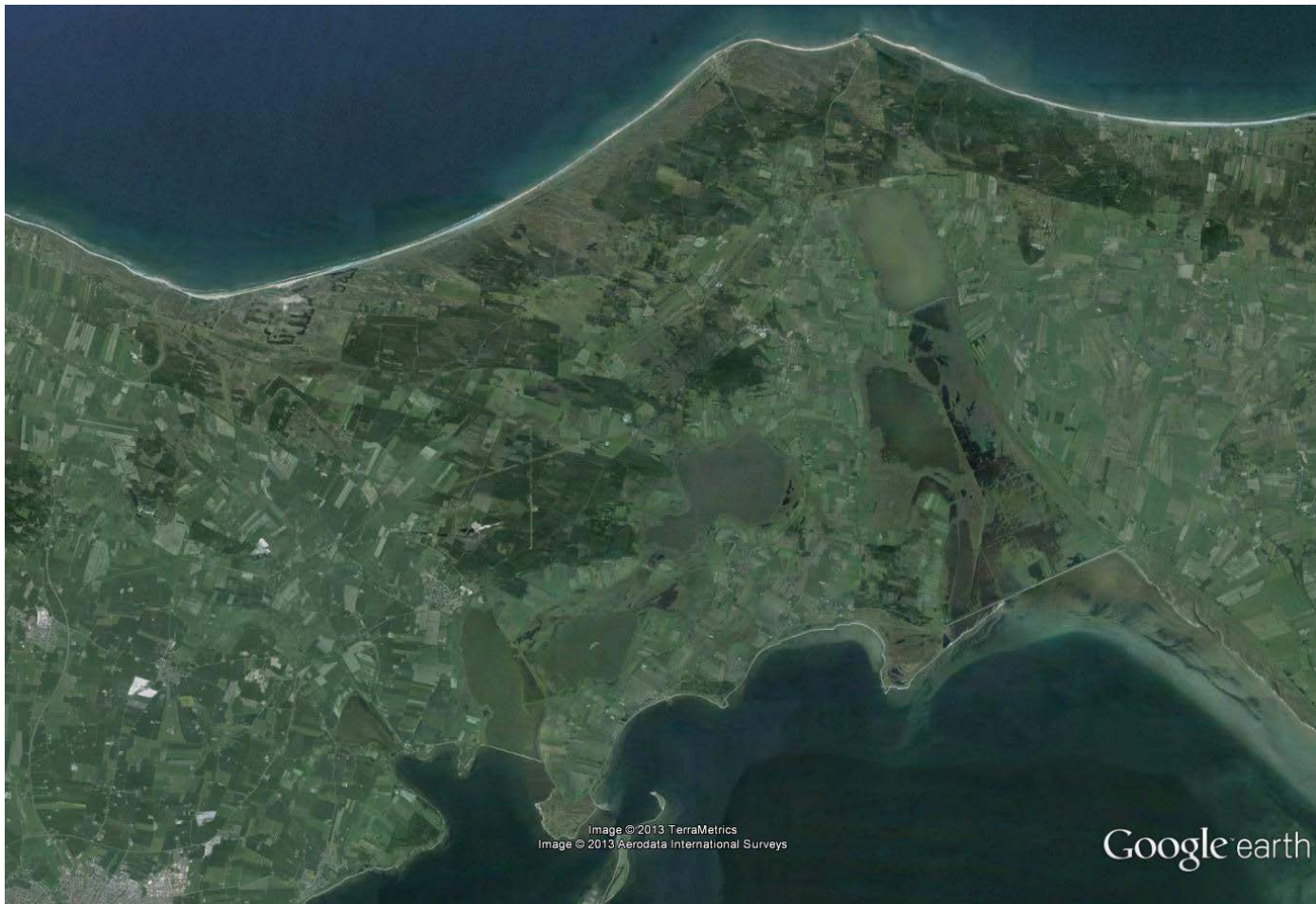
# Example: Forest



# Example: Forest

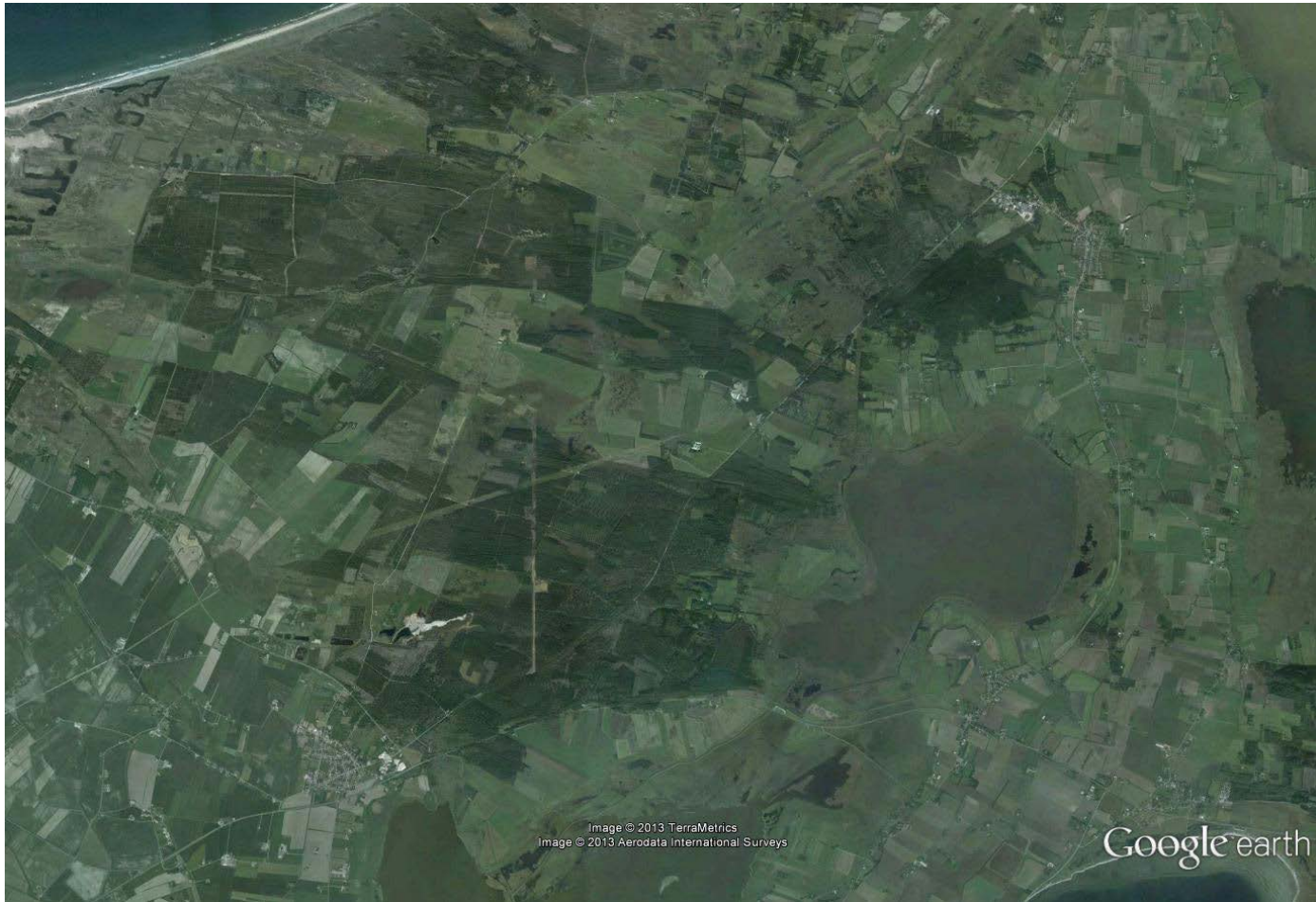


# Example: Forest

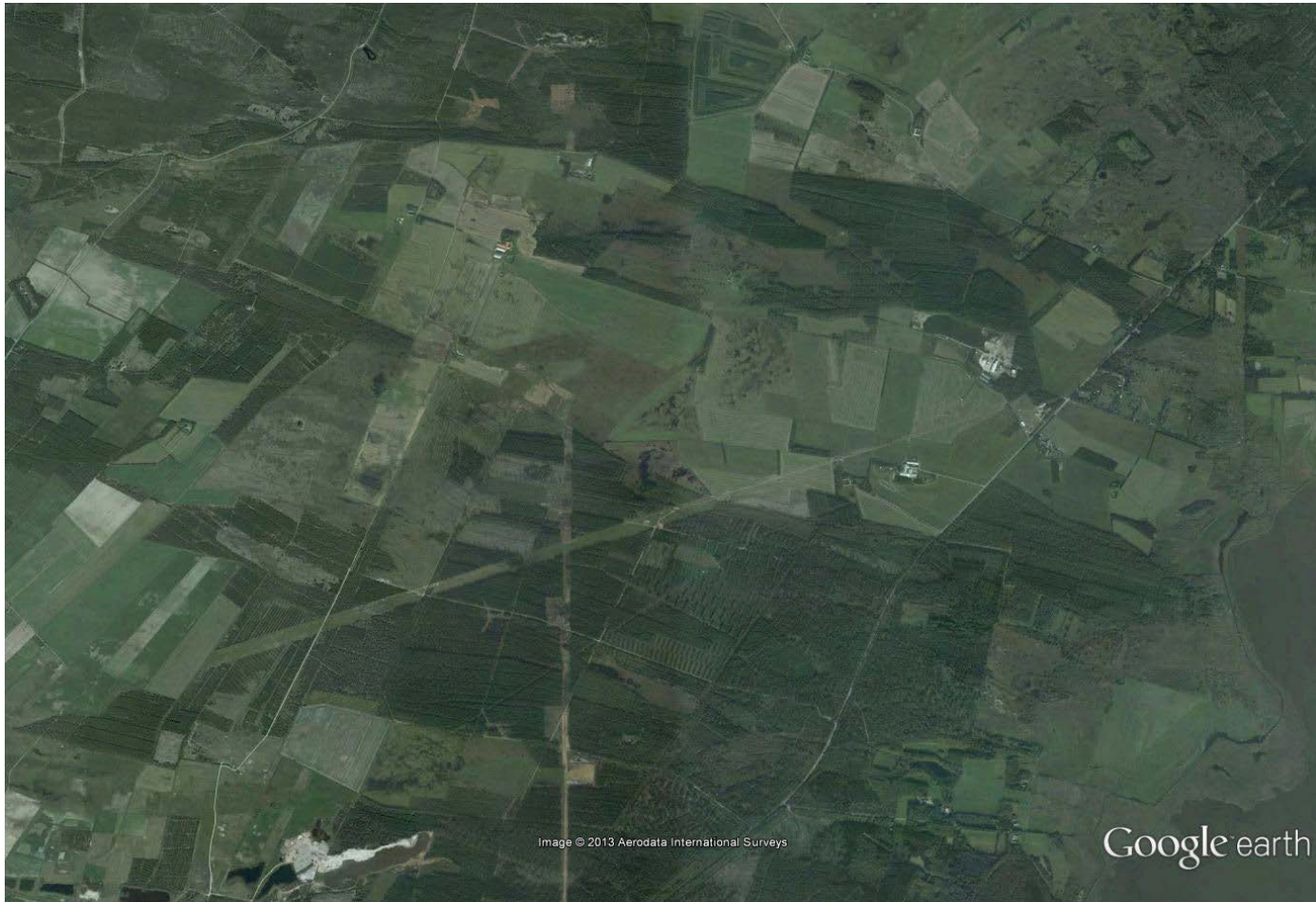




# Example: Forest

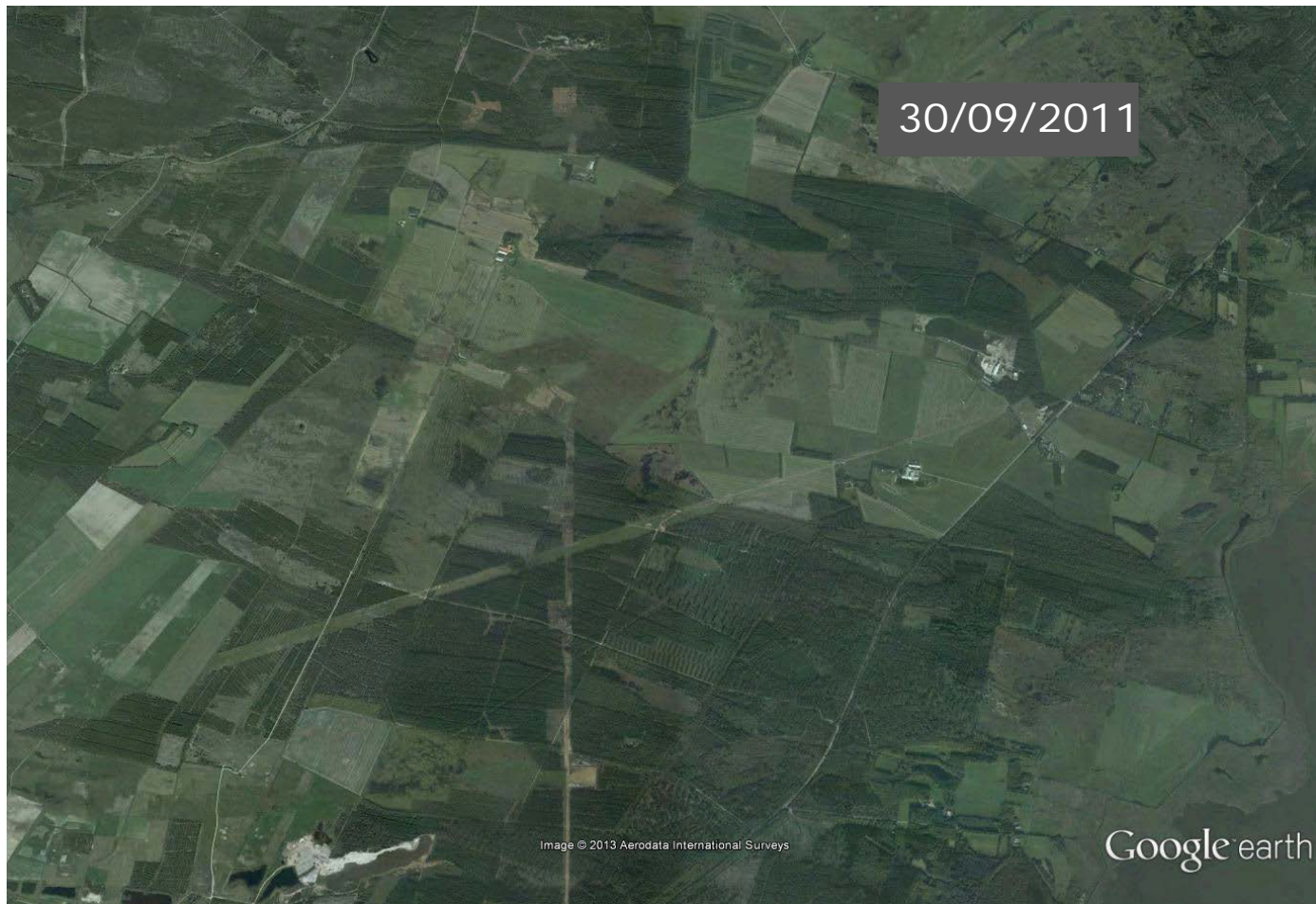


# Example: Forest





# Example: Forest





# Example: Forest



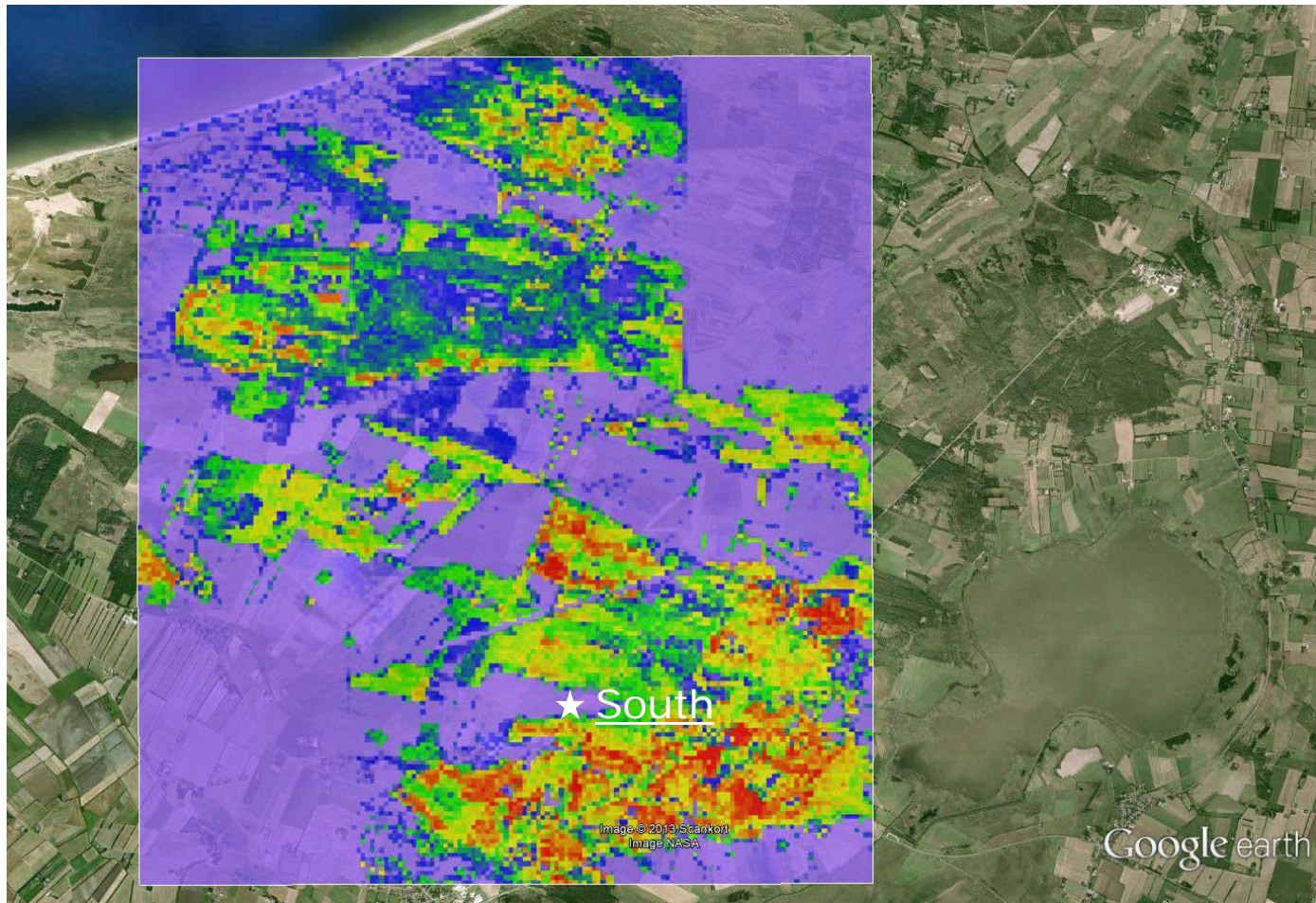


# Example: Forest

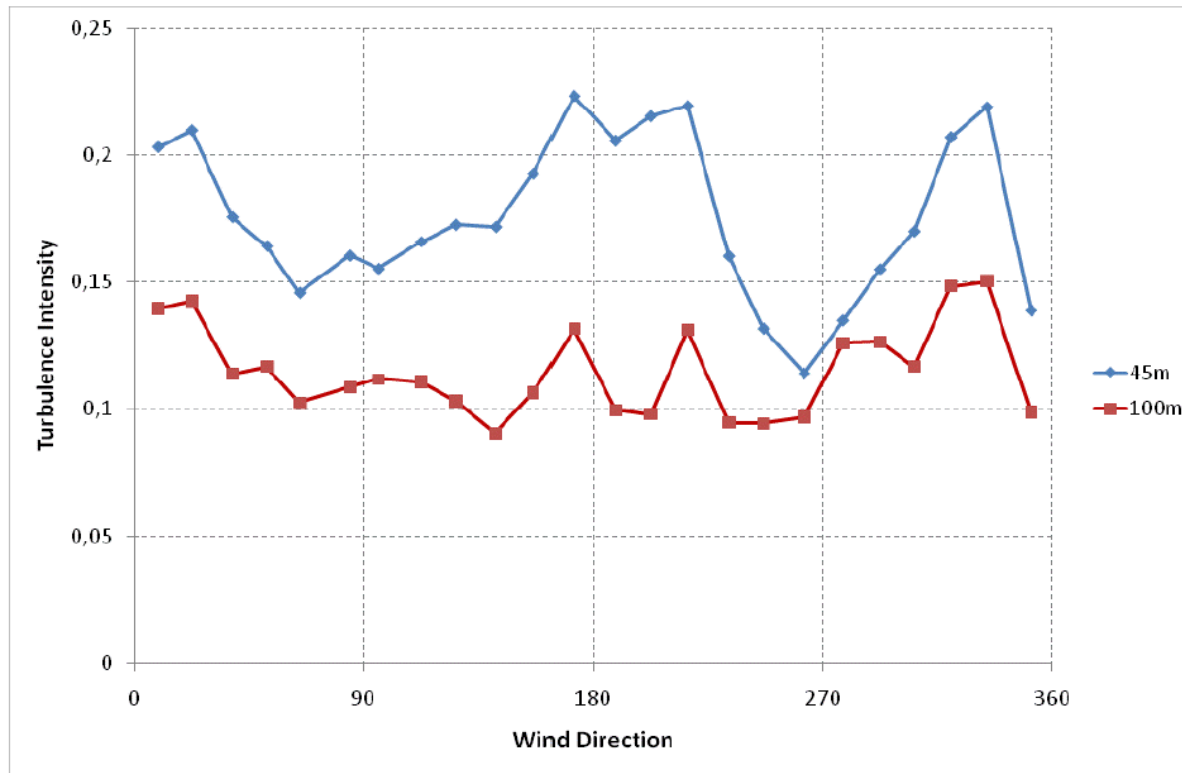




# Example: Forest



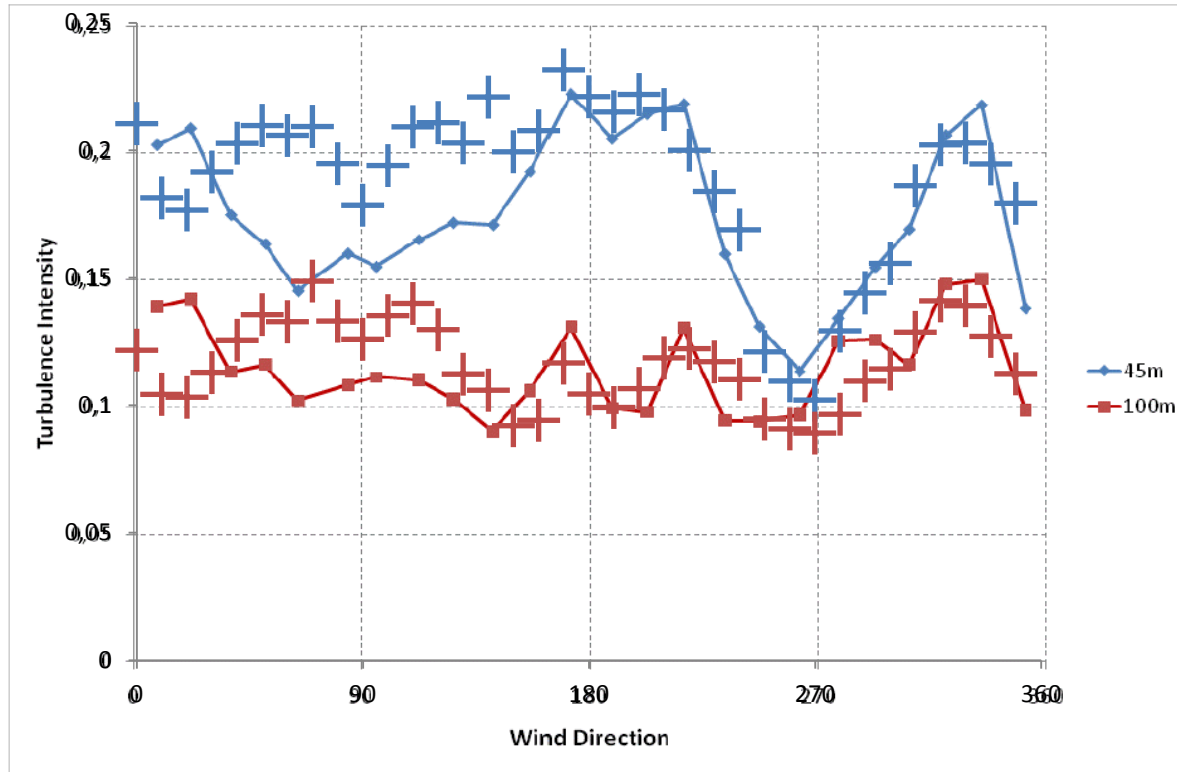
# Example: Forest



Figur 22 Turbulensintensitet som funktion af vindretning ved målestation Syd for 45m målehighde (blå) og 100m målehighde (brun).

# Example: Forest

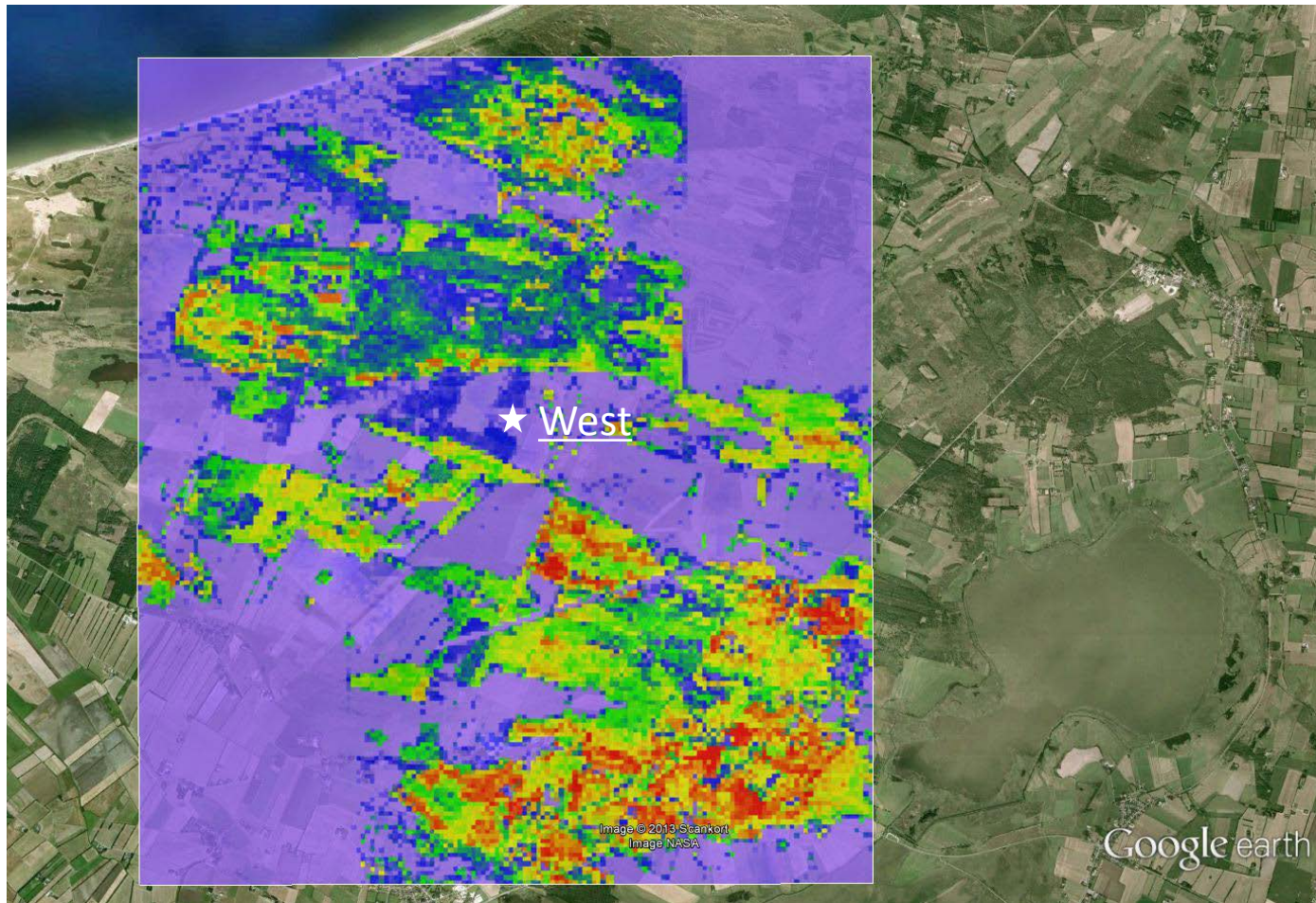
Turbulence Intensity at South  $cmu=0.05$



Figur 22 Turbulensintensitet som funktion af vindretning ved målestation Syd for 45m måleheight (blå) og 100m måleheight (brun).



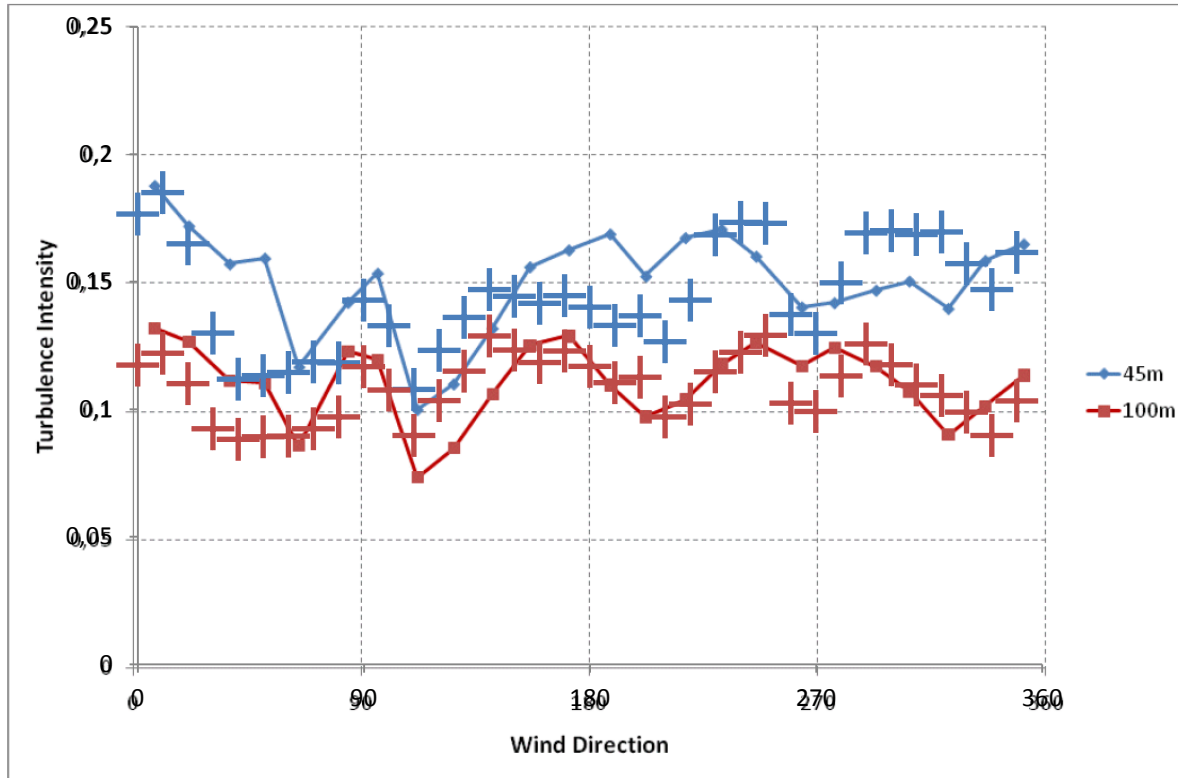
# Example: Forest





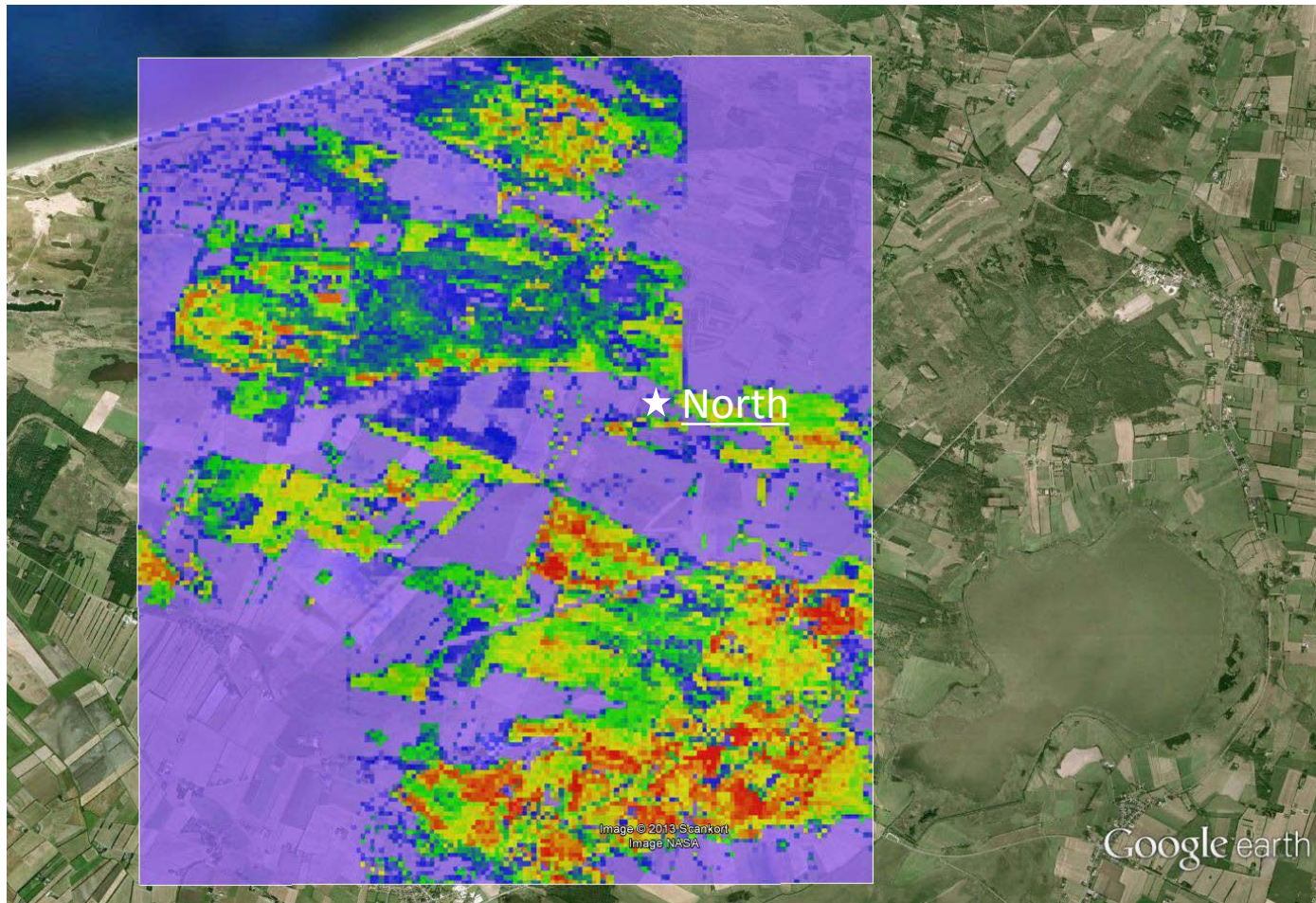
# Example: Forest

Turbulence Intensity at west  $\text{cmu}=0.05$



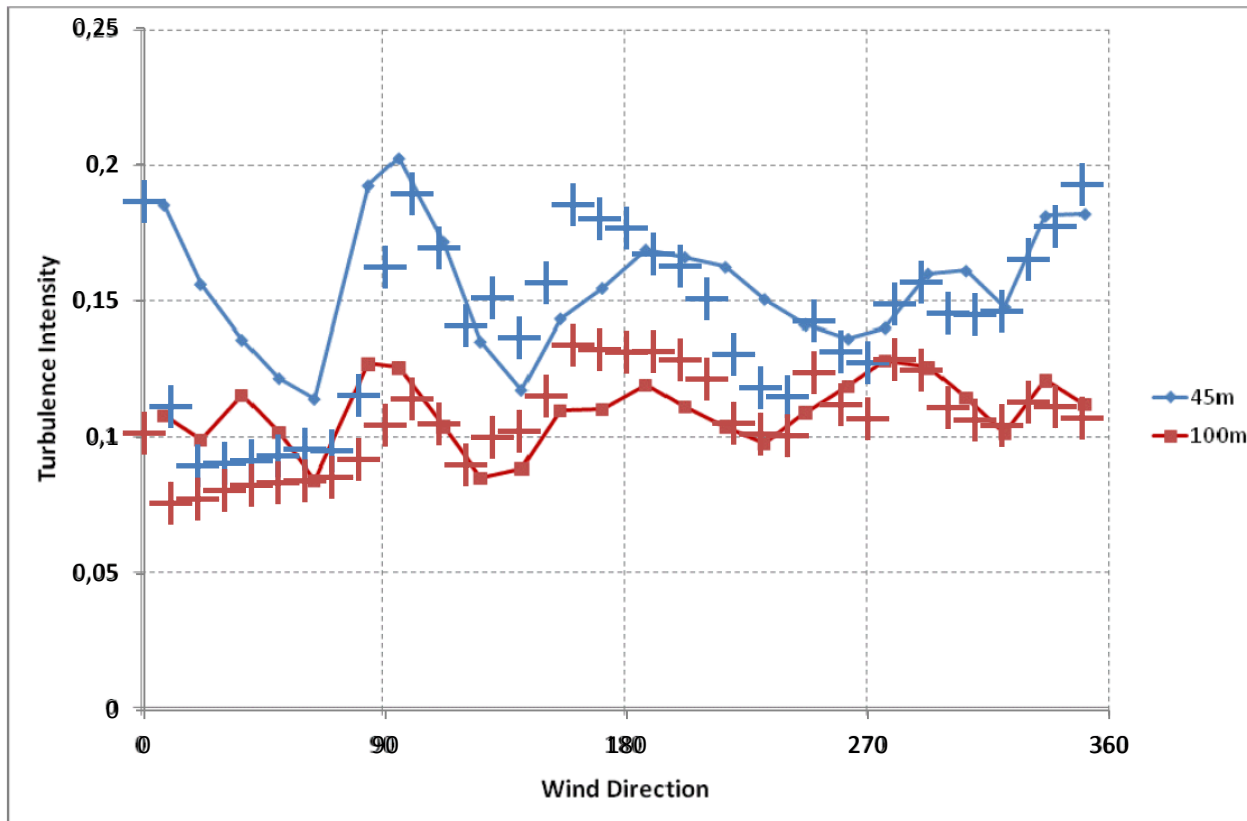
Figur 20 Turbulensintensitet som funktion af vindretning ved målestation Vest for 45m målehighde (blå) og 100m målehighde (brun).

# Example: Forest



# Example: Forest

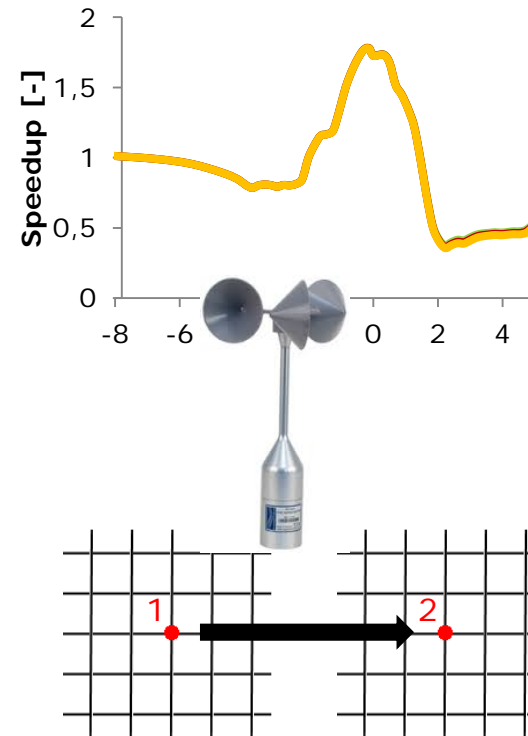
Turbulence Intensity at north  $cmu=0.05$



Figur 21 Turbulensintensitet som funktion af vindretning ved målestation Nord for 45m målehighøjde (blå) og 100m målehighøjde (brun).

# Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy
2. A model cannot predict wind resources; it extrapolates measurements
3. A method to couple micro- and meso-scales is needed
4. Farfield conditions should balance the meso-scale mean



A.Bechmann

